AD-A066 934 COLD REGIONS RESEARCH AND ENGINEERING LAB HANOVER N H F/G 4/2
ANALYSIS OF THE MIDWINTER TEMPERATURE REGIME AND SNOW OCCURRENC--ETC(U)
SEP 78 M A BILELLO, G C APPEL
UNCLASSIFIED CRREL-78-21 NL

1 OF 1
AD
A066934

END
DATE
FILMED
6-79
DDC

CRREL REPORT 78-21

LEVEL

U.S. ARMY CORPS OF ENGINEERS

Analysis of the midwinter temperature regime and snow occurrence in Germany

For conversion of SI metric units to U.S./British customary units of measurement consult ASTM Standard E380, Metric Practice Guide, *published by the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.*

Cover: Comparison of LANDSAT photo image taken on 17 March 1973 over southeastern West Germany with a topographic map of the same area showing isolines of the average January air temperature. Note the similarity in the extent of the snow field in the satellite photo and the corresponding outline of the topographic contours on the map.

12

CRREL Report 78-21

Analysis of the midwinter temperature regime and snow occurrence in Germany

Michael A. Bilello and G. Cameron Appel

September 1978

Prepared for
DIRECTORATE OF FACILITIES ENGINEERING
OFFICE, CHIEF OF ENGINEERS
By
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
U.S. ARMY CORPS OF ENGINEERS
HANOVER, NEW HAMPSHIRE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: CRREL Report 78-21
2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): 6 ANALYSIS OF THE MIDWINTER TEMPERATURE REGIME AND SNOW OCCURRENCE IN GERMANY,
5. TYPE OF REPORT & PERIOD COVERED
6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): 10 Michael A. Bilello ~~and~~ G. Cameron Appel
8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire 03755 — 17 A1
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 16 DA Project 4A762730AT42, Task A1, Work Unit 010
11. CONTROLLING OFFICE NAME AND ADDRESS: Directorate of Facilities Engineering, Office, Chief of Engineers, Washington, D.C. 20314
12. REPORT DATE: 11 September 1978
13. NUMBER OF PAGES: 48
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 12 56 p.
15. SECURITY CLASS. (of this report): Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report): Approved for public release; distribution unlimited. — 14 CRREL-78-21
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)
18. SUPPLEMENTARY NOTES

ORIGINAL CONTAINS COLOR PLATES: ALL DDC REPRODUCTIONS WILL BE IN BLACK AND WHITE

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Cold regions
Germany (East and West)
Meteorological data
Snow
Temperature history

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This study investigates the possibility of providing estimates of the time of occurrence and length of the freezing season for any location in East and West Germany by using the average January air temperature (AJAT) as an index. The results indicate that reliable values of the mean freezing index can be obtained from the AJAT relationships which are developed for Germany. This association is further verified using data from the northeastern part of the U.S., and the AJAT is then used to determine the average starting and ending dates (and hence the probable length) of the freezing season for stations in Germany. The AJAT and the average dates of snowfall occurrence for numerous locations in the U.S. and Germany are also correlated. Interrelationships between these parameters and the average CONT

DD FORM 1473, 1 JAN 73 — EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified 037 100 xlt

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. Abstract (cont'd)

CONT

number of days with snow on the ground for stations up to 3000 m in elevation in Germany are examined. A detailed AJAT map for East and West Germany, in which data from 134 stations, latitude, altitude and regional influences are considered, is developed in order to make the relationships usable. A historical review of the literature on snow studies in Germany and a brief discussion of snow-cover interpretation by satellite photography are included.

PREFACE

This report was prepared by Michael A. Bilello, Meteorologist, of the Snow and Ice Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory, and by G. Cameron Appel, formerly a Research and Development Coordinator at CRREL. Funding for this research was provided by DA Project 4A762730AT42, *Design, Construction and Operations Technology for Cold Regions*, Task A1, *Ice and Snow Technology*, Work Unit 010, *Freezing Season and Snow Occurrence in Central Europe.*

Gunars Abele, L. David Minsk and Lawrence Gatto of CRREL technically reviewed the manuscript of this report.

The authors acknowledge the encouragement and assistance received from Dr. George Ashton and William Quinn during the preparation of this report and the continued support of the project provided by Dr. Kay Sterrett and Albert Wuori.

CONTENTS

	Page
Abstract	i
Preface	iii
Introduction	1
Historical literature review	1
Relationships between midwinter temperature and freezing season	4
Mean freezing index	4
Average January air temperature	7
U.S. comparative study	8
Correlation of AJAT and duration of freezing season	11
Relationships between average January air temperature and snow conditions	11
U.S. relationships	11
German relationships	15
Mapping of average January air temperatures	21
Analysis of observed AJAT data	21
Development of detailed maps	26
Application and discussion	28
Examples	28
Influence of vegetation	29
Literature cited	29
Appendix A. Interpretation of snow cover by satellite	33
Appendix B. Contour, station elevation and AJAT maps for East and West Germany	41

ILLUSTRATIONS

Figure

1. Freezing index and freezing season for three stations in Germany ... 5
2. Relationship between freezing index and length of freezing season for 17 stations in Germany ... 5
3. Average monthly temperature curve for four stations in Germany ... 8
4. Relationship between the average January air temperature and the mean freezing index for stations in Germany and New England ... 8
5. Relationship between the average January air temperature and the average length of the freezing season for 17 stations in Germany ... 10
6. Relationship between the average January air temperature and the average starting and ending dates of the freezing season for 17 stations in Germany ... 10
7. Relationship between the average date of the first 1-in. snowfall of the season and the average January air temperature for 134 U.S. stations located at elevations of less than 750 m ... 13
8. Location of 24 stations in the U.S. where average dates of the first 1-in. of snowfall of the season are earlier than at stations with similar AJAT's ... 14
9. Relationship between the date of earliest snowfall of the season and the average January air temperature for stations in East and West Germany ... 17
10. Relationship between the date of latest snowfall of the season and the average January air temperature for stations in East and West Germany ... 17

Figure		Page
11.	Minimum air temperature curves for stations in Germany	18
12.	Relationship between the number of days between the dates of earliest and latest snowfalls of the season and the average number of days with snow on the ground in Germany	18
13.	Relationship between average January temperature and average number of days with snow on the ground for 12 stations with elevations below 600 m in or near East and West Germany	19
14.	Relationship between station elevation and average number of days with snow on the ground for 4 stations with elevations greater than 600 m in Germany	19
15.	Relationship between AJAT and elevation separated regionally by zones in Germany	23
16.	Locations of seven different climatic zones in Germany	24
17.	Relationship between AJAT and elevation for stations above 500 m in Germany	25

TABLES

Table		
I.	Mean freezing index, average January air temperature, and temperature at midpoint of the MFI curve for stations in East and West Germany	6
II.	Average starting and ending dates and length of the freezing season	6
III.	Statistics on the relationships between the variables shown in Figures 2, 4, 5, and 6.	7
IV.	Mean freezing index and average January air temperature for stations in New England, U.S.A.	9
V.	Average date of first 1-in. snowfall and average January air temperature for 134 first-order stations in the United States	12
VI.	Earliest and latest snowfall dates for stations in or near East and West Germany	15
VII.	Number of days between earliest and latest snowfalls, and average number of days with snow on the ground per year for stations in or near East and West Germany	16
VIII.	Location, elevation and average January air temperature for the stations in and near East and West Germany	16
IX.	Location, elevation and average January air temperatures for 95 stations in East and West Germany	22
X.	Statistics on the linear relationship between the variables shown in Figures 15 and 17	26

ANALYSIS OF THE MIDWINTER TEMPERATURE REGIME AND SNOW OCCURRENCE IN GERMANY

Michael A. Bilello and G. Cameron Appel

INTRODUCTION

Lack of information on localized or regional coverage of snow conditions, length of the freezing season and other wintertime characteristics is often encountered during attempts to answer questions on such subjects for specific areas. However, this information is often necessary for road construction purposes, repair of runway damage due to frost effects, and for other civilian and military activities. In order to improve estimates of the distribution of the winter temperatures, a knowledge of the geographical and topographical variations that occur in a region is usually required. This report investigates these regional environmental conditions and provides relationships between the average January air temperature and the occurrence of certain snowfall events.

Maps which show the areal distribution of snowfall frequencies, snow amounts, and snowcover depths have been developed for regions as large as continents or as small as football fields. An example of a study which incorporated snow data collected over a very large area is given in a series of maps on the depth of the snow cover for the Northern Hemisphere (U.S. Army 1954). Other examples are a mesoscale analysis of snow data for the six New England states conducted by Lautzenheiser (1968), and a localized investigation of the snow conditions on a military reservation in central Alaska performed by Bilello et al. (1972).

A review of the reports showed that snow data from about 420 stations were used for the hemisphere maps; 95 stations were used for the six New England maps, and 19 sites for the map of the 20-×40-km region in central Alaska. No attempts were made in these studies to utilize relationships between snow conditions and other climatic parameters or physical features to supplement the observed data. Snow information from additional stations would have provided more detail and undoubtedly would have improved the maps presented in the above reports. Likewise, the reliability of this information would have been improved through analysis of the relationships among pertinent meteorological parameters as was shown by Clapp (1967). Such an approach was taken in the study described in this report.

A region in central Europe was selected as a prime interest area for this study. A literature review revealed that some basic information on snow conditions was available for a number of stations in and near East and West Germany. Preliminary maps of the first and last days of snowfall and the length of the snow season based on these limited data were developed. However, further analysis of the data indicated that informational coverage could be improved by utilizing climatic records and elevation variations in delineating snow and temperature distribution. In this study, therefore, the various climatic relationships are investigated, a detailed midwinter temperature map is developed, and diagrams to estimate some snow conditions for Germany are presented.

The selection of East and West Germany for this study was also based on the strategic military significance of West Germany and the United States commitment to the defense of Western Europe (de Borchgrave 1977). The NATO Armies and the U.S. troops stationed in West Germany are often conducting field maneuvers and testing new tactics in preparation for possible aggressive military action (Middleton 1976, and Larsen 1976). The deployment, protection, and support of men and machines in winter require useful air temperature and snow information to enhance the successful planning and execution of these activities. The results presented in this study attempt to provide such information.

HISTORICAL LITERATURE REVIEW

A review of available literature* on snowfall and snow-cover conditions in Germany provided tabulations

* This "available literature" includes all references pertinent to this study listed in the comprehensive and continuing *Bibliography on Cold Regions Science and Technology* by CRREL at the Library of Congress (U.S. Army 1951-78).

of observed data and results of research on particular aspects of the subject. The earliest available study on snow conditions in Germany was on the duration of the snow cover in the Erz mountains of Saxony by Birkner (1890). The regional duration of the snow cover in these mountains is discussed on the basis of observations from 1884 to 1889 at 90 stations ranging in elevation from 94 to over 900 m. The average number of snow-cover days varied with elevation from 55 to 150 days. Meteorological factors which caused deviations from the influence of elevation were snowfall frequency, snow depth, number of days with negative temperatures, and solar radiation.

Research activity on snow in Germany between 1900 and 1930 was relatively minimal. During that period, only 12 investigations directly related to the subject under study were uncovered in the literature survey. Many of the studies conducted during this 30-year period pertained to snow conditions at specific sites. For example, the results of measurements at Aachen from 1887 to 1902 are reported by Sieberg (1902). Data on 15 years of record at this location provided the mean monthly number of days with snowfall, dates of the first and last snowfalls and snow cover, and monthly mean snow-cover frequencies. Similar studies were conducted for the city of Berlin by Lachmann (1902), for the Black Forest region by Klute (1911), and for Baden by Malsch (1923).

Snow depth and duration observations made between 1885 and 1919 throughout Germany were analyzed in a series of reports published in the 1910's and 1920's. Stegers (1913), and Lachmann and Schwalbe (1916) investigated snow conditions in northern Germany; Lengacker (1910) studied southern Germany, and Hebner (1928), using data collected at 150 stations throughout Germany, investigated the annual number of snow-cover days. Hebner noted that the duration of the snow cover in Germany is primarily dependent on air temperature. This relationship will be investigated in detail below.

Two other reports published in the 1920's, Hellmann (1921) and Dieckmann (1929), investigated snow precipitation in Germany and the relationship between its occurrence and factors such as temperature and elevation. They found, for example, that the first snowfall on the German plain occurs in October and the last in May; at higher elevations these events occur in September and June, respectively. However, the total number of days with snowfall during these winter months varies from only 19 days in the Upper Rhine Valley to over 190 days at Zugspitze (elevation 2962 m).

A marked increase in the number of studies on snow conditions in Germany occurred during the decade 1930-39, and this was followed by an apparent decrease in *available* reports on such studies during the 1940's. This decrease may be due to World War II, when much of the completed research was either destroyed or never archived, or when less research was carried out.

Most of the studies conducted during the 1930's pertain to the snow-cover conditions observed at particular cities or specific locations. Dieckmann (1930) examined the frequency and duration of periods of unbroken snow cover at Rugen (on the Baltic Sea), Haeuser (1933) tabulated and graphed the depth and water content of new snow covers observed in München (Munich), and Peppler (1934) characterized the conditions of the snow cover in the Black Forest with respect to skiing and winter sports. Dieckmann (1935) conducted a study that was similar, and for the same purpose, as Peppler's, but for the Swabian Hill region in south Germany. Metzler (1935) provided a chronological account of the formation and decay of the snow cover at Brocken during the winter of 1934-35. Schwalbe (1936), Greim (1939), and Kuhnke (1939) provided information on snow precipitation, snowfall amounts and snowstorm intensity by using long-term records and/or information on specific storms. In Kuhnke's paper, the distribution, frequency and intensity of 57 snowfalls of 15 mm per 24 hours or more are investigated. Major snowstorms and the meteorological conditions conducive to heavy snowfalls observed during the period 1881 to 1936 are also discussed by Kuhnke.

In the early 1940's the Reichsamt für Wetterdienst (1942) published some articles in which the snow conditions in Russia, Poland and North Germany are compared. In later years the name of this agency was changed to Deutscher Wetterdienst, and it published a number of climatic atlases for specific regions in Germany (e.g. Deutscher Wetterdienst 1953). Naegler (1943) published data on monthly snow precipitation in Dresden for October through May from 1926 to 1943, and Meissner (1943) correlated air temperatures with days of snowfall in Berlin for December through March. The Dresden study, for example, showed that the average proportion of snow in the combined precipitation (i.e. total water equivalent) for the entire year was 9.6% or 75.4 mm. The amounts ranged from 20.6 mm of snow in 1929-30 to 155.3 mm in 1940-41. The number of days with snow on the ground during these two winters varied from 12 to 60, and averaged 36 days over the period 1926 to 1943. However, the snow cover each winter at Dresden did not necessarily remain continuously on the ground for a long time. The longest duration for a snow cover observed during the period of record that Naegler studied was 17 days (from 26 January to 11 February 1935).

The 1950's experienced a decided revival in snow research activities in Germany. However, the studies again concentrated on single locations or specific regions in Germany. Weischet (1950) tabulated and graphed data on snow-cover duration for 20 locations in the Rhenish Slate Mountains of Germany and analyzed the relationship of this parameter to synoptic meteorological conditions. His results showed that the average number of days with snow cover varies from 10 days (at 44-m elevation) to 104 days (at 780 m), and the average maximum snow-cover depth varies from 5.8 cm (at 44 m) to 95 cm (at 780 m). Additional papers on snow-cover duration and snow depths were published by Schulz (1952) for the Oberharz-Clausthal region, by Reinhard (1952) and Knepple (1953) for the Griefswald-Mecklenburg area, and by Mollwo (1953) for the West German hill country. A compilation of snow-cover data for a larger region of central and west Germany was made by Brose (1952). The survey showed that, over a two-year record, maximum snow depths in the areas studied occurred in 1940-41 and 1941-42. It was also noted that winters of maximum snow depths do not necessarily coincide with the winters with maximum numbers of days with snow cover.

Evaluation of snow conditions observed at certain locations continued during the 1960's. Weigel (1960) measured and mapped the distribution of snow on Brocken Mountain, Antonik (1961) analyzed snowfall data collected at the Potsdam Observatory (East Germany), and Pleiss (1961) tabulated the distribution of snow precipitation as well as the beginning and end of snowfall and snow cover on Fichtelberg (the second highest peak in the Erzgebirge Mountains, East Germany). Pleiss showed that snow or snow mixed with rain accounted for 44% of the total precipitation in this area, and that there are approximately 100 days per year with snow precipitation. However, the total number of days with snow cover during a single winter varied between 107 and 217 days. Antonik and Boer (1962) and Reichel (1965) also conducted studies on the proportion of snow in the total precipitation for various parts of Germany. Antonik and Boer, using data from about 80 climatological stations at elevations from 200 to 1000 m, computed the variations of the snow component in precipitation and showed that the percentage increase in snowfall amounts increased directly with the height of the station above sea level. New concepts for determining the boundary of the snowline in the southern Black Forest of Germany were presented by Haase (1966). The methods included the delineation of temporary, local, and orographic snow boundaries and climatic approaches in which regional or ideal snow boundaries were defined.

Numerous studies on snow-cover conditions in the Alps have, of course, been conducted; practically all of these investigations, however, pertain to areas within the borders of Switzerland. In recent investigations, for example, Lauscher (1969) associates mean monthly snow depths with mean maximum values for the Eastern Alps; Haefner et al. (1974) describe the development of a semiautomated system to map snow cover in the Swiss Alps and discuss the accuracy of the areal measurements using ERTS-1 images from different MSS bands. Numerous other reports on snow conditions in Switzerland are available in the publication, "Snow and avalanches in the Swiss Alps" (Rychetnik 1971), which recently has been published annually. However, since no attempt will be made to include any part of Switzerland in this study, an extensive review of the literature on snow in that area has been omitted.

Thomas and Alt (1972) provide hourly, weekly and monthly tables and graphs of the amount and distribution of snow and ice on the federal highways of West Germany during the winter of 1970-71. Eschner and Brechtel (1973) describe a snow survey network that has been in operation since the winter of 1967-68 in the State of Hessen in West Germany. The State of Hessen includes an area of about 21,110 km^2 and its major cities are Frankfurt, Wiesbaden, Darmstadt, Kassel, Offenbach, and Giessen. A series of studies on the data collected indicated that, on the average, the greatest snow accumulation occurred in stands on north and east-facing slopes, and that, although accumulation increased with elevation, the snowpack was also important at elevations below 300 m.

The titles of some major reports are misleading with respect to their association to the specific subject of this paper. For example, a report by Bekker and Legget (1947) is entitled, "Snow studies in Germany." However, this report does not discuss snowfall events, but examines snow as it affects vehicular mobility, the efficiency of snow blowers, snow removal on highways, use of snow fences and hedges, development of propeller sleds in Germany, and research on avalanches in the Tyrol and Carpathian Mountains.

It should be noted that this historical literature review intentionally excluded references on snow-cover densities, the water equivalent of snowfall, the hydrologic aspects of the snow cover, and many of the numerous investigations on the distribution of snow depths in Germany. These particular parameters are omitted because they are not within the scope of this study. Furthermore, this review does not purport to be all-inclusive, since no effort was made to extend the survey to all possible pertinent national or international literature sources.

RELATIONSHIPS BETWEEN MIDWINTER TEMPERATURE AND FREEZING SEASON

Schulz (1965), using climatic information from 73 winters in the Harz region of Germany, showed that optimal snow accumulations occur at negative temperature deviations of 2.0° to 2.9°C below the normal. During positive temperature deviations, deficits in snow-cover amounts were observed to increase rapidly as soon as the temperature deviations exceeded 1°C. Antonik (1961), using snowfall and snow cover data collected since 1893 at Potsdam, found that snow covers of long duration were associated with abnormally cold winters and that a strong correlation exists between mean winter temperatures and the amount of snow cover. Similar air temperature and snow-cover relationships were noted by the authors of other studies as has been discussed previously. In order to determine whether climatic records of the air temperature at weather stations throughout Germany could be used to estimate specific winter conditions, the associations between pertinent parameters are examined in detail.

Prior to investigating the relationships between negative air temperatures and snow conditions, the possibility of using a simple and easily available numerical value (such as an average midwinter air temperature) to represent the winter freezing regime at each station was examined.

In the following discussion, therefore, analysis of the freezing season for East and West Germany will include: 1) mean and midwinter temperatures, 2) length of the freezing season, and 3) average starting and ending dates of the freezing season.

Mean freezing index

The combined duration and magnitude of below-freezing temperatures occurring during any given winter is defined as the freezing index. The index determined for air temperatures observed at 4.5 ft ($\simeq$ 1.37 m) above the ground is commonly designated as the air-freezing index, while that determined for temperatures immediately below a surface is known as the surface freezing index (see Huschke 1959). The freezing degree-days for any one day equal the difference between the average daily air temperature and 32°F (U.S. Army and Air Force 1966a). Conventionally, the degree-days are negative when the average daily temperature is below 0°C (freezing degree-days) and otherwise positive (thawing degree-days). Figure 1 shows three curves obtained by plotting cumulative degree-days vs time for climatological normal temperature records at Berlin, München and Brocken, Germany (U.S. Dept. of Commerce 1974). The cumulative freezing degree-days or mean freezing index (MFI) can be expressed as

$$\mathrm{MFI} = \sum_{0}^{n} (T_{\mathrm{i}}) \qquad (1)$$

where 0 is the first day when the long-term average air temperature falls below 0°C, n the number of days with freezing temperatures, and T_{i} the average temperature for each day. As shown in Figure 1, n = 145 days (12 November to 5 April) and the MFI = − 449 freezing degree-days (base 0°C) for Brocken.

No attempt was made to complete the thawing degree-day curves for the stations in Figure 1. The reason is that, beyond the cutoff points shown, the spring thawing and concurrent snow-melting period has ended, and consequently the remaining part of the curve is not required for this study. However, a portion of the beginning of the thawing degree-day curve (as presented) becomes important, especially at locations with deeper snow covers where the number of days with snow on the ground during the period of melting and ablation can be extensive.

Another value on the mean freezing index curve given in Figure 1 worthy of discussion at this time is the date at which the midpoint occurs:

$$\frac{\mathrm{MFI}}{2} \approx \frac{1}{2} \sum_{0}^{n} (T_{\mathrm{i}}). \qquad (2)$$

For example, at Brocken the MFI midpoint would be −449/2 = −224.5, which occurs on 25 January. Similarly, the dates for the other stations are 18 January for Berlin and 17 January for München. This date indicates the time in winter when the minimum temperature occurs; later, this temperature will be compared with the corresponding average January air temperature (AJAT) at each station.

The three stations shown in Figure 1 were selected as examples because they are located in different regions within Germany, experience some variation in winter air temperatures and snow conditions, and are situated at altitudes ranging from 49 to 1152 m. The symmetrical similarity of the curves indicates that a positive relationship exists between the length of the freezing season and the freezing index. The degree of certainty in the relationship is shown in Figure 2, in which the mean freezing index for 17 stations in East and West Germany (Table I) is plotted vs the corresponding length of the freezing season (average number

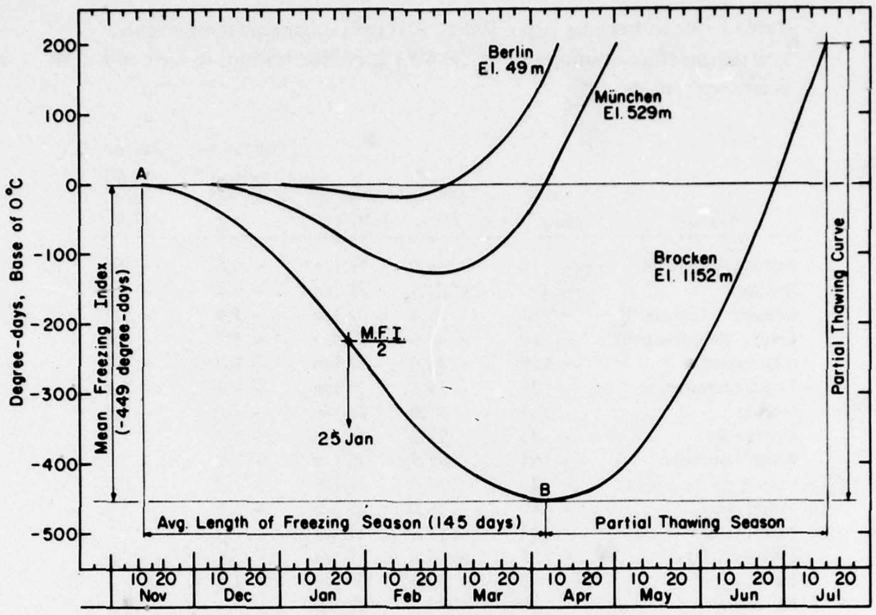


Figure 1. Freezing index and freezing season for three stations in Germany. (Detailed example is given for Brocken, in which A to B represents Brocken's MFI.)

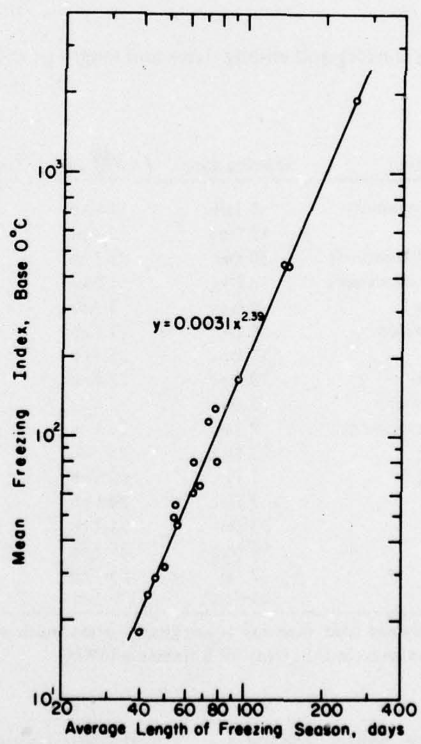


Figure 2. Relationship between freezing index and length of freezing season for 17 stations in Germany.

Table I. Mean freezing index (MFI), average January air temperature, and temperature at midpoint of the MFI curve for stations in East and West Germany.*

Station	MFI (base °C)	MFI/2 (°C)	Date of MFI/2	Temp on date of MFI/2 (°C)	Average Jan air temp (°C)
Berlin (Tempelhof)	– 18	– 9.0	18 Jan	– 0.6	– 0.6
Brocken	– 449	–224.5	25 Jan	– 4.8	– 4.6
Dresden (Wahnsdorf)	– 55	– 27.5	25 Jan	– 1.4	– 1.2
Erfurt (Bindersleben)	– 80	– 40.0	23 Jan	– 1.7	– 1.6
Fichtelberg	– 448	–224.0	27 Jan	– 5.9	– 5.7
Friedrichshafen	– 29	– 14.5	20 Jan	– 0.8	– 0.8
Gorlitz	– 114	– 57.0	26 Jan	– 2.2	– 2.0
Greifswald	– 46	– 23.0	26 Jan	– 1.2	– 1.0
Kaltennordheim	– 165	– 82.5	26 Jan	– 2.8	– 2.6
Leipzig (Schkeuditz)	– 32	– 16.0	25 Jan	– 1.0	– 0.8
Lindenberg	– 80	– 40.0	23 Jan	– 1.6	– 1.5
Magdeburg	– 25	– 12.5	21 Jan	– 0.7	– 0.7
München	– 128	– 64.0	17 Jan	– 2.4	– 2.4
Neustrelitz	– 61	– 30.5	25 Jan	– 1.5	– 1.3
Nürnberg	– 65	– 32.5	22 Jan	– 1.4	– 1.4
Potsdam	– 49	– 24.5	26 Jan	– 1.3	– 1.1
Zugspitze	–1895	–947.5	26 Jan	–11.8	–11.6

* Computations made from information given in U.S. Dept. of Commerce (1974).

Table II. Average starting and ending dates and length of the freezing season.*

Station	Starting date	Ending date	Length of freezing season (days)
Berlin (Tempelhof)	1 Jan	11 Feb	42
Brocken	12 Nov	5 Apr	145
Dresden (Wahnsdorf)	30 Dec	22 Feb	55
Erfurt (Bindersleben)	13 Dec	1 Mar	79
Fichtelberg	9 Nov	3 Apr	146
Friedrichshafen	28 Dec	11 Feb	46
Gorlitz	15 Dec	25 Feb	73
Greifswald	30 Dec	23 Feb	56
Kaltennordheim	3 Dec	7 Mar	95
Leipzig (Schkeuditz)	2 Jan	20 Feb	50
Lindenberg	22 Dec	23 Feb	64
Magdeburg	1 Jan	12 Feb	43
München	7 Dec	24 Feb	80
Neustrelitz	23 Dec	24 Feb	64
Nürnberg	15 Dec	20 Feb	68
Potsdam	2 Jan	24 Feb	54
Zugspitze	21 Sep	9 Jun	262

* Dates obtained from monthly temperature curves developed from information given in U.S. Dept. of Commerce (1974).

of days with negative temperatures per winter) for the same stations (Table II).

Statistical evaluation of the relationship between the variables shown in Figure 2 (and others presented below) was conducted by computer computation. The evaluation included 1) a regression analysis, 2) determination of the equation for the line of best fit and the correlation coefficient and 3) a t-ratio test on the sets of data. A tabulation of these statistical computations for the relationships investigated in this section

Table III. Statistics on the relationships between the variables shown in Figures 2, 4, 5, and 6.

Figure no.	*Type of regression*	*Equation of best fit**	*Correlation coefficient (r)*	*t-ratio test value*
2	log-log	$y = 0.0031x^{2.39}$	0.970	30.9
4 (Line A)	log-log	$y = -41.2\lvert x\rvert^{1.50}$	0.986	47.7
4 (Line B)	log-log	$y = -52.0\lvert x\rvert^{1.25}$	0.974	41.9
5	linear	$y = 35.4 - 20x$	0.970	31.7
6 (Line A)	linear	$y = 369 + 9.6x$	0.920	18.8
6 (Line B)	linear	$y = 38.8 - 10.4x$	0.953	24.5

* x and y values are identified in the text.

of the report is given in Table III. Notice that in all cases the correlation coefficient exceeds 0.9 in both the log-log and linear regression analyses. The t-ratio test values also were excellent and indicate that the data sets are significant to the 0.001 percentile level. Because Zugspitze was located at an elevation more than twice that of Fichtelberg, the next highest station (2962 vs 1215 m), a test was conducted to determine what the effect would be if the Zugspitze data were excluded from the group of 17 stations. Since only minor deviations in the statistical results were noted in the test, the data for Zugspitze remained in the analyses shown in Table III.

The association obtained in Figure 2 for the 17 stations in Germany provides considerable confidence with attempts to associate certain freezing related temperature parameters, as presented in this study. In this case, for example, it shows that, if the average freezing season for a station in Germany lasts for 100 days, the mean freezing index would be about 200 °C-days. However, even though the regression analysis on the data given in Figure 2 provided reasonable correlation, this relationship was not used in this study because 1) considerable work is involved in computing freezing indices, and 2) subsequent analyses showed that the average January air temperature (AJAT) is an excellent index for determining the length of the freezing season. Use of the AJAT was also less time-consuming and provided results comparable to those given by the calculations obtained from eq 1.

The length of a freezing season can be shown by plotting a mean monthly air temperature curve for each station (Fig. 3). The climatological normal temperature values given by the U.S. Dept. of Commerce (1974) were used to draw this diagram. Similarities between the curves shown in Figure 1 and the curves for the same three stations in Figure 3 should be noted. Observe, for example, that the date at the start of the freezing index curve in Figure 1 coincides with the starting date of average freezing air temperatures in Figure 3, and similarly that the date of the inflection point at the lower end of the curves in Figure 1 coincides with the last average freezing temperature dates for each station in Figure 3. As mentioned earlier, these dates define the length of the freezing season. Incidentally, the area enclosed by the negative temperatures in Figure 3 approximates the mean freezing index values obtained from eq 1.

Average January air temperature (AJAT)

The similarity in the general shape of the curves presented in Figures 1 and 3 suggested the possibility that a point on the curves for each station could be used to obtain acceptable estimates of the freezing indices and length of the freezing season. The idea was to identify (with confidence) *one* commonly available air temperature value which can be used to ascertain the information given by the curves in Figures 1 and 3.

The association, therefore, between the AJAT for 17 stations in Germany (Table I) and the corresponding MFI was first investigated. The results are shown by line A of Figure 4. A log-log plot was used in this relationship because the MFI values ranged from −18 at Berlin to −1895 at Zugspitze. Results of the statistical evaluation for the relationship shown in Figure 4 are given in Table III. The correlation coefficient for line A was 0.986 and the t-ratio test was significant to the 0.001 percentile level. The equation for line A

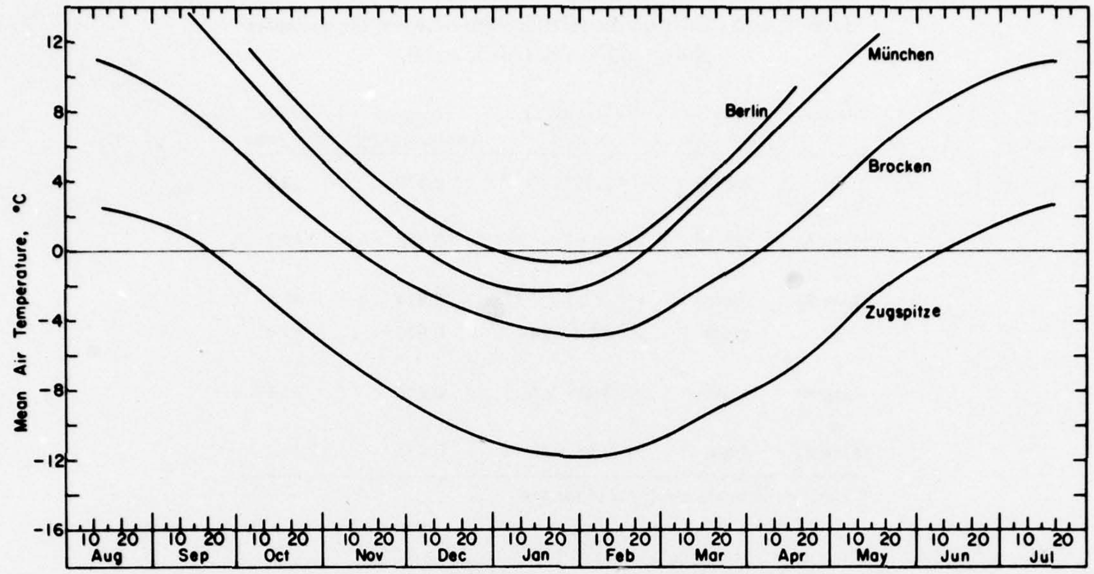


Figure 3. Average monthly temperature curve for four stations in Germany.

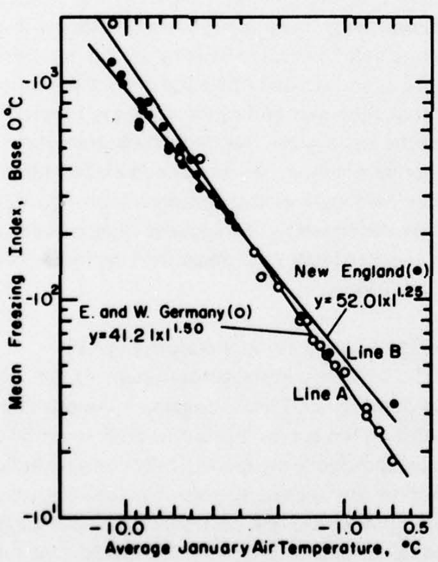


Figure 4.** **Relationship between the average January air temperature and the mean freezing index for stations in Germany (Line A) and New England (Line B).

in Figure 4 is

$$y = -41.2|x|^{1.50} \tag{3}$$

where $|x|$ is the absolute value of the AJAT, and y the MFI (base 0°C).

Another method of calculating the daily departures from the freezing temperature was developed by Boyd (1976) to eliminate the tedious computation of daily values. Boyd devised a method of using normal monthly mean temperatures to compute normal freezing and thawing degree-days in changeover months with adequate accuracy. Boyd's study differs from the results given in this report in two main respects:

1. Boyd's study is principally concerned with the changeover months when the freezing and thawing temperatures need to be separated, whereas the approach used here directly includes the freezing portions of these changeover months in the relationship.
2. Boyd's calculations require normal monthly mean temperatures for more than one month, whereas the approach used here includes only the AJAT.

U.S. comparative study

For comparison purposes, and also because so few points were available at AJAT values of between −3.0° and −12.0°C for this study, a similar investigation for 26 stations throughout the northeastern region of the United States was conducted. The MFI values and the AJAT for the New England stations are given in Table IV. A plot of these values (Fig. 4, line B) shows good agreement with that obtained for the data from Germany and also yielded excellent correlation values. The correlation coefficient for the U.S. data was 0.974, and the t-ratio test results are satisfactory (see Table III). The equation for line B in Figure 4 is

Table IV. Mean freezing index and average January air temperature for stations in New England, U.S.A.*

Station	*Mean freezing index (base °C)*	*Average January air temperature (°C)*
Amherst, Massachusetts	-275	-3.8
Bangor (Dow Field), Maine	-625	-6.8
Bethlehem, New Hampshire	-751	-8.4
Burlington, Vermont	-659	-8.8
Caribou, Maine	-1277	-11.9
Chestnut Hill, Massachusetts	-56	-1.2
Clinton, Massachusetts	-218	-3.2
Cornwall, Vermont	-488	-6.5
Cream Hill, Connecticut	-308	-4.1
Eastport, Maine	-447	-5.1
Enosburg Falls, Vermont	-822	-8.8
Fitchburg (Fort Devens), Massachusetts	-234	-3.4
Gardiner, Maine	-509	-6.4
Greenville, Maine	-997	-10.4
Hoosac Tunnel, Massachusetts	-421	-5.6
Kingston, Rhode Island	-84	-1.6
Manchester, New Hampshire	-328	-4.6
Pittsfield Airport, Massachusetts	-490	-5.7
Plymouth, Massachusetts	-33	-0.6
Portland, Maine	-497	-5.7
Presque Isle, Maine	-1103	-10.6
Rumford, Maine	-626	-8.9
Somerset, Vermont	-819	-8.1
Stockbridge, Massachusetts	-380	-4.8
Woodland, Maine	-709	-7.9
Worcester, Massachusetts	-249	-3.4

* Freezing index values obtained from Gilman (1964), and the January temperatures from U.S. Dept. of Commerce (1964).

$$y = 52.0|x|^{1.25} \qquad (4)$$

where $|x|$ is the absolute value of the AJAT and y the MFI (base 0°C). The resultant similarity in the equations shown in Figure 4 makes it possible to quickly compute freezing indices by simply using the AJAT. Note that no attempt is made to extend the lines in Figure 4 beyond AJAT's of less than −0.5°C. Consequently, the given equations are meant to apply within the range of data defined by the lines of best fit as shown in the Figure 4.

As noted earlier, the air temperature occurring at the midpoint of a freezing index curve should correspond favorably with the AJAT. This test was conducted for the stations in Germany and is shown in the last two columns of Table I. The comparisons for all stations fall within a ± 0.2°C difference in temperature, thus far justifying use of the vastly more simplified and easily available independent variable, the AJAT.

Having established that the average January air temperature can be used to determine the freezing index for stations in Germany, it follows that the same value can perhaps be used to obtain estimates of the length of the freezing season and possibly the first and last average freezing dates. As noted earlier, the length of the freezing season (in days) is obtained from a temperature curve derived from a plot of the mean monthly winter air temperatures (see Fig. 3). The first freezing day is the date when the curve intersects 0°C in autumn or early winter, and the last freezing day occurs on the date that the curve again intersects 0°C in late winter or spring. The interval between these dates is the length of the freezing season. These two dates and the number of days between them for 17 stations under study in Germany are given in Table II. A plot of these sets of data for each station is shown in Figure 5 and the correlation coefficient in the linear regression analysis is 0.970. The equation for the line shown in Figure 5 is

$$y = 35.4 - 20x \qquad (5)$$

where x is the AJAT, and y the length of the freezing season (days). The relationship shows that, for stations in Germany where the AJAT is less than −3.0°C, the

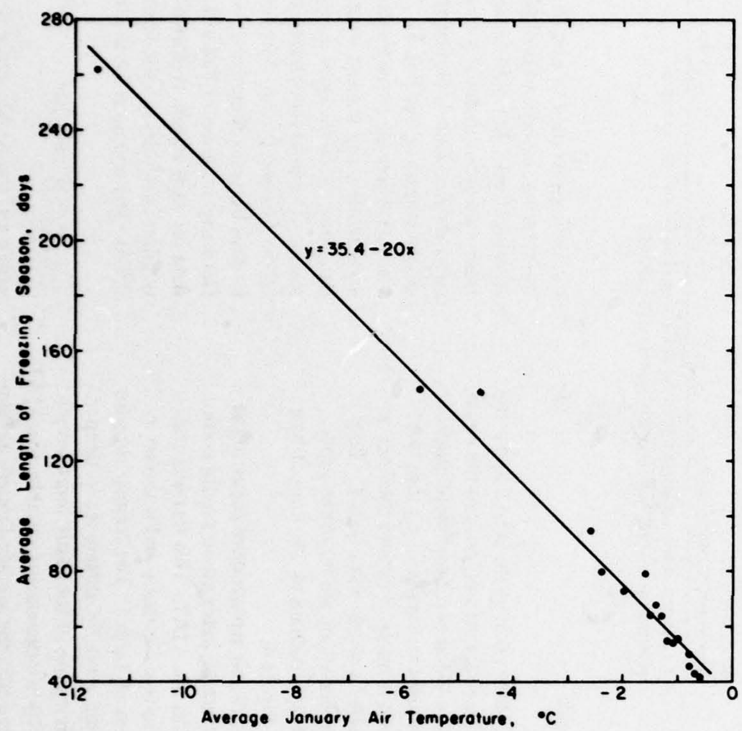


Figure 5. Relationship between the average January air temperature and the average length of the freezing season for 17 stations in Germany.

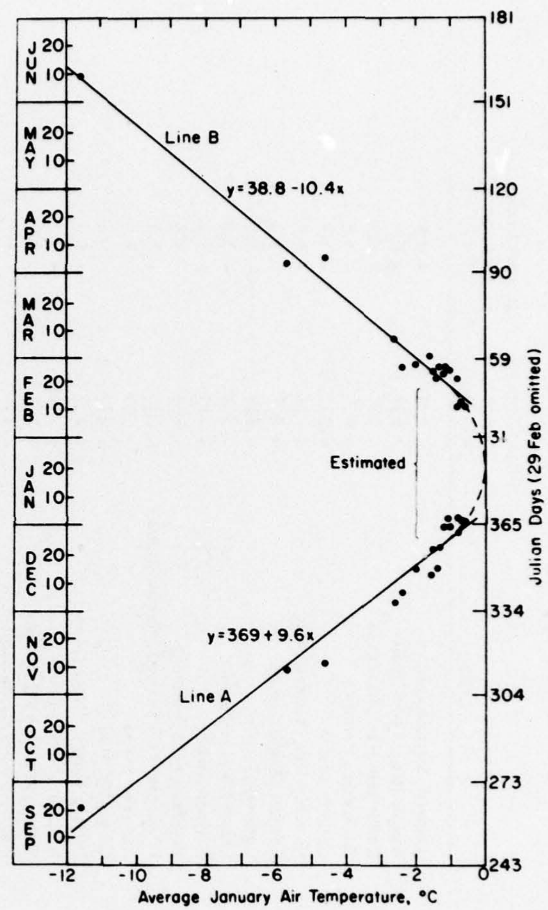


Figure 6. Relationship between the average January air temperature and the average starting (Line A) and ending (Line B) dates of the freezing season for 17 stations in Germany.

average length of the freezing season is probably under 100 days. At colder sites where the AJAT is between –4°C and –6°C, the freezing season lasts about 20 weeks, and at extremely cold places like Zugspitze, an AJAT colder than –11°C means that daily freezing air temperatures can be expected during 70% of the year.

Correlation of AJAT and duration of freezing season

The association of the starting and ending dates of the freezing season with the AJAT for the 17 stations in Germany was also investigated, and the results are shown in Figure 6, lines A and B. Line A identifies the regression equation for estimating the starting date of the freezing season:

$$y = 369 + 9.6x \tag{6}$$

and line B the regression equation for estimating the date of the end of the freezing season:

$$y = 38.8 - 10.4x \tag{7}$$

where x is the AJAT and y the average starting date (line A) or the average ending date (line B) of the freezing season. In the above equation, the Julian calendar numerical value obtained in the calculations can be converted to the equivalent Gregorian calendar date (where day 1 = 1 January, and 29 February is omitted). Values for both the Julian and Gregorian calendars are shown in Figure 6. The correlation coefficient and t-ratio test values for the lines in Figure 6 are given in Table III. At locations with high elevation where the AJAT is less than –10°C, the average freezing season starts during September; at warmer sites where the AJAT is between –1°C and –2°C, the average freezing season begins from mid to late December (Fig. 6, line A). Line B shows that the freezing season in the colder regions of Germany extends through late May-early June, but that it lasts only through late February in areas with an AJAT of –1 to –2°C. The dashed curve shown in Figure 6 (joining lines A and B) is an estimate of the relationship between the starting and ending dates of the freezing season for AJAT's of between 0 and –1°C.

It should be noted here that many stations in Germany have AJAT values greater than 0°C. This, of course, does not imply that the site experiences only above-freezing temperatures. It is obvious that during January, for example, a station could experience 10 days of daily air temperatures which average –2°C, followed by 16 days in which the daily air temperature averaged +2°C, resulting in a positive AJAT. Long-term averages, in fact, could also conceal abnormally long periods of freezing temperatures. This study does not attempt to predict or to evaluate the probabilities of extreme conditions. However, it does show that events of snow occurrence are recorded at sites that record AJAT's greater than 0°C (see below).

The tests given in this section have shown that the AJAT is a reliable and convenient index to use in determining the length and severity of a freezing season. Further investigations described in the following section were conducted to determine if the AJAT could also be used to estimate certain snow conditions.

RELATIONSHIPS BETWEEN AVERAGE JANUARY AIR TEMPERATURE AND SNOW CONDITIONS

Basic information on snow conditions for some sites or regions in Germany can be obtained from several of the sources given in the literature review. By using additional U.S. and German data, the relationship of the AJAT and certain snow conditions was investigated.

U.S. relationships

An indication of the potential use of the AJAT to estimate snow occurrences was obtained by examining the 1-in. (25.4-mm) threshold data presented by Thom (1957). Thom defines the 1-in. snowfall threshold as the first day in fall or winter during which 1 in. or more of snowfall occurs. In his study, Thom provides climatological statistics on this snowfall event for most of the first-order U.S. weather stations. These average dates of the AJAT for 134 stations throughout the U.S. are shown in Table V. Included in this tabulation are data from stations in 40 states, including Alaska and the District of Columbia. These sites represent a wide variety of winter environmental conditions and range in AJAT's from +10.7°C at Del Rio, Texas, to –23.9°C at Fairbanks, Alaska.

The two variables given in Table V were plotted in Figure 7, revealing two separate data sets. The linear regression (line A) in Figure 7 incorporates 110 of the 134 stations studied in which the equation is

$$y = 355 + 3.2x \tag{8}$$

where x is the AJAT and y the average date of the first 1-in. snowfall of the season. The correlation coefficient in the linear regression analysis for line A was $r = 0.927$ and the standard error of estimate for $y = \pm 5.9$ days. Note again that a Julian calendar numerical value is used in the equations given in Figure 7. The equivalent Gregorian date is also shown in the figure for conversion purposes. The 110 stations represented by line A incorporate a large range of AJAT's and show that the

Table V. Average date of first 1-in. snowfall and average January air temperature for 134 first-order stations in the United States.*

Station	Avg date of 1st 1-in. snowfall	Avg Jan air temp (°C)	Station	Avg date of 1st 1-in. snowfall	Avg Jan air temp (°C)
Anniston, Alabama	2 Feb	7.6	Binghamton, New York†	26 Nov	− 4.6
Birmingham, Alabama	24 Jan	8.1	Buffalo, New York†	19 Nov	− 4.1
Anchorage, Alaska†	26 Oct	−11.1	Canton, New York†	13 Nov	− 8.1
Fairbanks, Alaska	12 Oct	−23.9	New York, New York	19 Dec	0.9
Juneau, Alaska†	9 Nov	− 3.8	Oswego, New York†	22 Nov	− 3.8
Ketchikan, Alaska†	9 Dec	1.7	Rochester, New York†	21 Nov	− 3.8
Nome, Alaska	26 Oct	−15.3	Syracuse, New York†	16 Nov	− 4.4
Fort Smith, Arkansas	19 Jan	4.3	Asheville, North Carolina	26 Dec	3.1
Little Rock, Arkansas	15 Jan	4.8	Charlotte, North Carolina	16 Jan	5.9
Eureka, California	23 Jan	8.6	Greensboro, North Carolina	7 Jan	4.3
Red Bluff, California	6 Jan	7.5	Hatteras, North Carolina	12 Jan	8.7
Hartford, Connecticut	9 Dec	− 3.3	Raleigh, North Carolina	12 Jan	5.3
New Haven, Connecticut	11 Dec	− 1.3	Wilmington, North Carolina	20 Jan	8.8
Wilmington, Delaware	22 Dec	0.8	Bismarck, North Dakota	7 Nov	−12.3
Washington, D.C.	22 Dec	2.7	Devils Lake, North Dakota	9 Nov	−15.2
Atlanta, Georgia	17 Jan	7.1	Fargo, North Dakota	17 Nov	−13.7
Augusta, Georgia	17 Jan	8.7	Williston, North Dakota	11 Nov	−13.2
Macon, Georgia	22 Jan	9.6	Akron-Canton, Ohio†	27 Nov	− 2.1
Cairo, Illinois	30 Dec	3.0	Cincinnati, Ohio	16 Dec	0.9
Chicago, Illinois	6 Dec	− 4.3	Cleveland, Ohio†	28 Nov	− 2.0
Moline, Illinois	11 Dec	− 5.2	Columbus, Ohio	13 Dec	− 1.2
Peoria, Illinois	12 Dec	− 3.5	Dayton, Ohio	13 Dec	− 1.3
Springfield, Illinois	17 Dec	− 2.0	Sandusky, Ohio	8 Dec	− 1.5
Evansville, Indiana	24 Dec	1.2	Toledo, Ohio	7 Dec	− 3.2
Fort Wayne, Indiana	7 Dec	− 2.8	Oklahoma City, Oklahoma	8 Jan	2.8
Indianapolis, Indiana	15 Dec	− 1.6	Tulsa, Oklahoma	28 Dec	2.3
Terre Haute, Indiana	19 Dec	− 1.8	Portland, Oregon	10 Jan	3.7
Burlington, Iowa	4 Dec	− 4.2	Medford, Oregon	4 Jan	1.9
Charles City, Iowa	26 Nov	− 9.6	Roseburg, Oregon	11 Jan	4.7
Davenport, Iowa	8 Dec	− 5.2	Erie, Pennsylvania†	13 Nov	− 3.7
Des Moines, Iowa	5 Dec	− 6.7	Harrisburg, Pennsylvania	13 Dec	− 0.4
Dubuque, Iowa	1 Dec	− 7.1	Philadelphia, Pennsylvania	22 Dec	0.2
Keokuk, Iowa	13 Dec	− 3.9	Pittsburgh, Pennsylvania†	3 Dec	− 1.7
Sioux City, Iowa	24 Nov	− 7.4	Reading, Pennsylvania	13 Dec	0.4
Concordia, Kansas	15 Dec	− 2.5	Scranton, Pennsylvania†	3 Dec	− 2.4
Topeka, Kansas	12 Dec	− 1.8	Block Island, Rhode Island	28 Dec	0.1
Wichita, Kansas	18 Dec	0.0	Providence, Rhode Island	15 Dec	− 1.6
Lexington, Kentucky	15 Dec	1.4	Columbia, South Carolina	11 Jan	8.3
Louisville, Kentucky	22 Dec	1.7	Greenville, South Carolina	16 Jan	6.5
Shreveport, Louisiana	15 Jan	8.6	Huron, South Dakota	22 Nov	−10.8
Eastport, Maine	25 Nov	− 5.1	Chattanooga, Tennessee	5 Jan	5.4
Portland, Maine	30 Nov	− 5.7	Knoxville, Tennessee	3 Jan	5.2
Baltimore, Maryland	26 Dec	1.6	Nashville, Tennessee	6 Jan	4.4
Boston, Massachusetts	14 Dec	− 1.2	Abilene, Texas	15 Jan	7.0
Nantucket, Massachusetts	25 Dec	0.6	Austin, Texas	22 Jan	10.2
Alpena, Michigan†	17 Nov	− 6.8	Dallas, Texas	11 Jan	7.7
Detroit, Michigan†	1 Dec	− 2.8	Del Rio, Texas	17 Jan	10.7
Escanaba, Michigan†	21 Nov	− 7.5	Fort Worth, Texas	13 Jan	7.5
Grand Rapids, Michigan†	21 Nov	− 4.4	Burlington, Vermont	18 Nov	− 8.8
Lansing, Michigan†	22 Nov	− 4.3	Northfield, Vermont†	11 Nov	− 7.9
Marquette, Michigan†	2 Nov	− 6.9	Cape Henry, Virginia	16 Jan	5.9
Sault Ste. Marie, Michigan†	3 Nov	− 9.0	Lynchburg, Virginia	2 Jan	3.1
Duluth, Minnesota	13 Nov	−12.9	Norfolk, Virginia	12 Jan	5.1
Minneapolis, Minnesota	20 Nov	−10.9	Richmond, Virginia	2 Jan	3.7
Meridian, Mississippi	29 Jan	8.9	North Head, Washington	17 Jan	4.6
Vicksburg, Mississippi	20 Jan	9.4	Seattle, Washington	2 Jan	3.5
Columbia, Missouri	19 Dec	− 1.5	Spokane, Washington	27 Nov	− 3.7
Kansas City, Missouri	12 Dec	− 0.2	Tacoma, Washington	26 Dec	3.5
St. Joseph, Missouri	16 Dec	− 2.7	Tatoosh Island, Washington	2 Jan	5.6
St. Louis, Missouri	21 Dec	− 0.1	Walla Walla, Washington	15 Dec	0.7
Springfield, Missouri	22 Dec	0.9	Yakima, Washington	11 Dec	− 2.5
Lincoln, Nebraska	7 Dec	− 3.8	Elkins, West Virginia†	23 Nov	0.3
Omaha, Nebraska	4 Dec	− 5.4	Parkersburg, West Virginia†	12 Dec	1.4
Concord, New Hampshire	26 Nov	− 6.0	Green Bay, Wisconsin	27 Nov	− 8.4
Atlantic City, New Jersey	3 Jan	− 1.6	La Crosse, Wisconsin	26 Nov	− 8.6
Trenton, New Jersey	19 Dec	0.6	Madison, Wisconsin	30 Nov	− 8.1
Albany, New York	2 Dec	− 5.2	Milwaukee, Wisconsin	3 Dec	− 6.3

* Snowfall dates obtained from Thom (1957) and temperature data obtained from U.S. Department of Commerce (1956, 1964).

† Earlier average occurrences of 1-in. snowfalls are observed at these locations and are shown in Line A in Fig. 7.

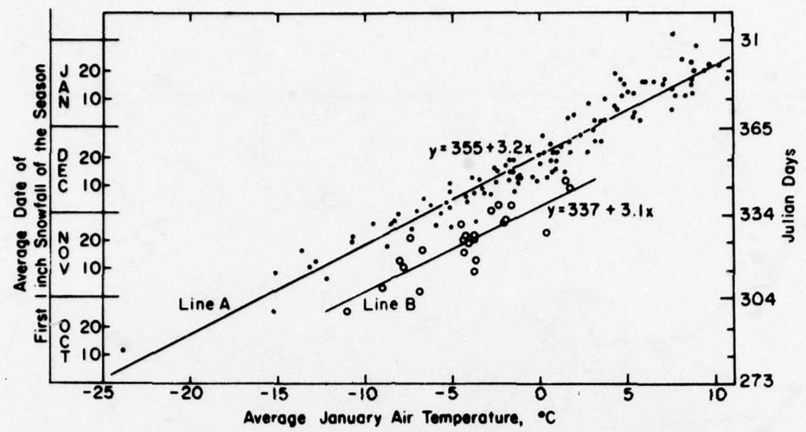


Figure 7. Relationship between the average date of the first 1-in. snowfall of the season and the average January air temperature for 134 U.S. stations located at elevations of less than 750 m. Open circles represent the 24 stations shown in Figure 8.

average date of the first 1-in. snowfall occurs early in October at locations recording AJAT's of less than −20°C, and after January for locations in the U.S. where the AJAT is greater than +5.0°C. An anomaly in the relationship was found for the 24 stations identified separately in Table V, which are included in line B of Figure 7. These locations experience, on the average, 1-in. snowfalls 15 days earlier than other stations with similar AJAT's, indicating a possible difference in environmental conditions.

These 24 stations, therefore, were located on a map to determine their position relative to each other and to identify possible common environmental conditions. The results are shown in Figure 8. Twenty-one of these 24 stations revealed a geographical bond in that they lie within a region defined by lines connecting each of the outermost stations located east and southeast of the Great Lakes. The remaining three stations are located in the south or southeast coastal areas of Alaska. Many of these 21 cities (for example, Buffalo and Oswego, New York; Erie, Pennsylvania, etc.) are located in a region which is influenced by "lake effect snowstorms." A description of one such snowstorm observed at Buffalo, New York, is given by Dietz and Kolker (1975), and further details on the causes and effects of these Great Lakes storms during the early winter are given in Weickmann et al. (1970) and Paine and Kaplan (1971). A satellite image of a 1975 snowstorm (McMillan and McGinnis 1975) showed the snow-covered parts of Michigan, northern Indiana and Ohio, western New York and Pennsylvania, and most of West Virginia forming a pattern similar to the one shown in Figure 8. The authors state that the storm displayed a clear example of lake effect and orographic snowfall, which was due to cold, dry air flowing southeastward to the lakes and gaining large amounts of heat and moisture. Early winter outbreaks of frigid air, therefore, produce measurable amounts of snow accumulations downwind of the Great Lakes, and so the region records slightly earlier 1-in. snowfalls (line B, Fig. 7). The early snowfalls at the stations in southeastern Alaska (Fig. 8) are probably also caused by conditions similar to those observed near the Great Lakes, i.e. the cold air moving over the warm Gulf of Alaska absorbs water and then releases the moisture as snow during orographic uplift along the coast.

It is important to discuss the limitations in the implications and use of the information provided in Figure 7. First, of course, is the awareness that each value shown in the diagram consists of an average for many years of data and, therefore, cannot be used as a forecast for a year-to-year event. Thom (1957) provides additional statistics on the 1-in. threshold quantiles for 0.05, 0.10, 0.30, and 0.90 probabilities which may be used for planning purposes. For example the probability of a threshold snowstorm occurring in Burlington, Iowa, before 23 October is 0.05, before 2 November is 0.10, before 21 November is 0.30, and before 6 January is 0.90. Another limitation is that locations in southern Texas, such as Del Rio where the AJAT is +10.7°C, obviously experience many winters when the station records no snow. Northern stations like Marquette, Michigan, and Providence, Rhode Island, probably experience 1-in. snowfalls every winter, but the timing for the period of 0.05 to 0.90 probability levels for Marquette varies from 8 October to 22 November

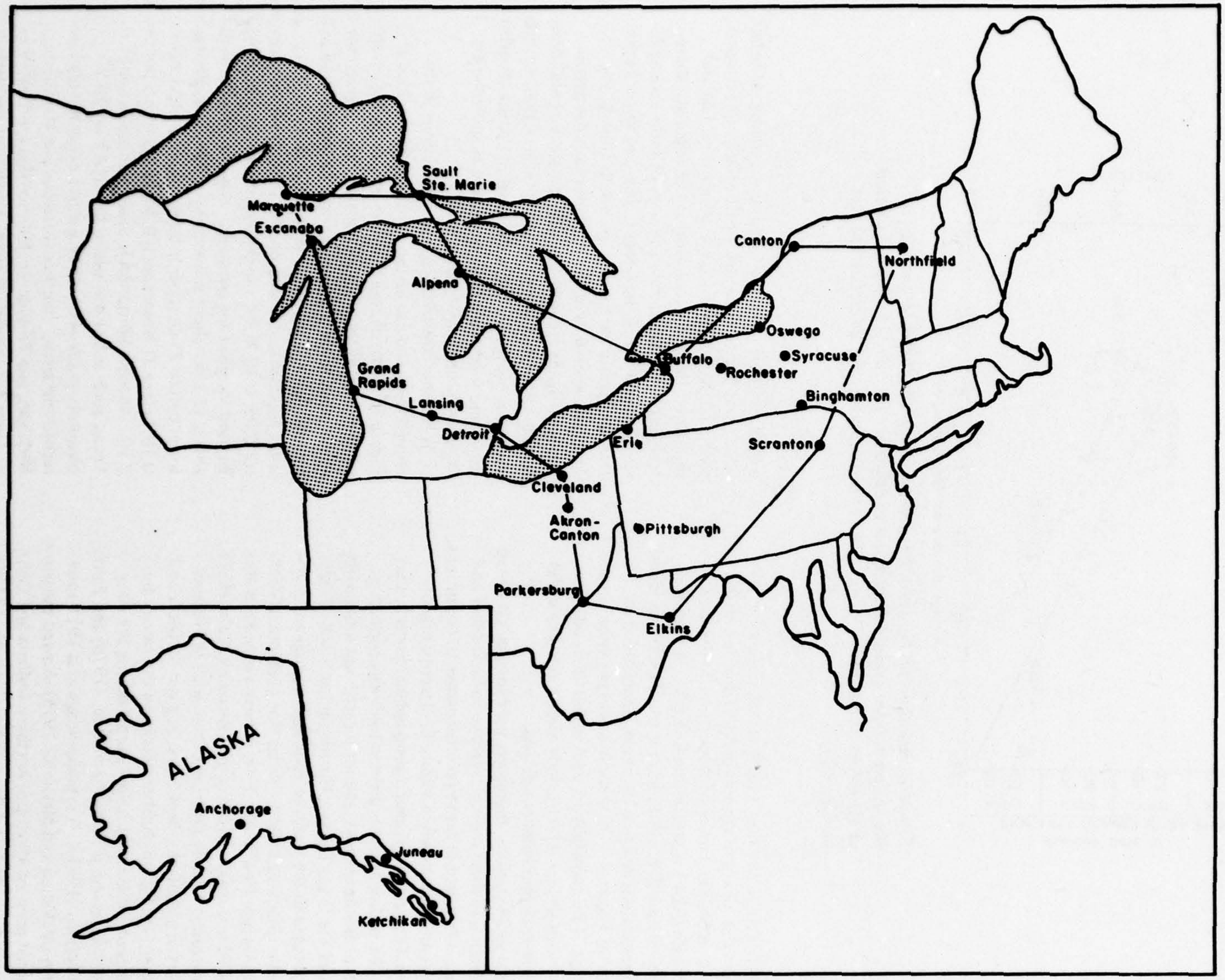


Figure 8. Location of 24 stations in the U.S. where average dates of the first 1-in. of snowfall of the season are earlier than at stations with similar AJAT's. Region enclosed by 21 continental sites is outlined.

(46 days), as compared to 10 November to 11 January (63 days) for Providence. Such variations in the likelihood for a 1-in. snowfall event occurring should be considered when using the average values given in this study.

Despite these limitations, the relationship shown in Figure 7 provided sufficient evidence to permit use of the AJAT to determine the occurrence dates of other snow events. The associations, therefore, between AJAT's and available records on snow information for East and West Germany were investigated.

German relationships

Standard climatic data including the date of earliest and latest snowfall (Table VI), and the average number of days per year with snow on the ground (Table VII) for a number of stations in East and West Germany were obtained from a U.S. Department of Commerce (1940) publication. The information contained in this publication was then correlated with the observed AJAT at each station (Table VIII).

Data on the dates of earliest and latest snowfall of the season observed at a station were available for 20 stations in or near East and West Germany (Table VI). Although it was not specifically stated in the original source, it is assumed that the recorded snowfall amounts on these dates were at least measurable, i.e. 1 mm or more. A trace of snow would not be included. Results of the relationships between these snow events and the associated AJAT's (Table VIII) are shown in Figures 9 and 10. Julian calendar dates are again used in the equations given in Figures 9 and 10. The regression analysis showed that for locations in Germany where the AJAT is near −3°C, first snowfalls of the season occur during late October and the last snowfalls during early May. At locations where the AJAT is near +2°C, the earliest and latest snowfalls of the season occur in early December and early April, respectively. The standard errors of estimate for y in the linear relationships were 4.4 days in Figure 9 and 3.6 days in Figure 10.

Table VI. Earliest and latest snowfall dates for stations in or near East and West Germany (U.S. Dept. of Commerce 1940).

Station	*Date of earliest snowfall of the season*	*Date of latest snowfall of the season*
Berlin (Tempelhof)	19 Nov	15 Apr
Bremen	17 Nov	9 Apr
Flensburg	13 Nov	12 Apr
Frankfurt	19 Nov	5 Apr
Freiburg	19 Nov	10 Apr
Friedrichschafen	15 Nov	13 Apr
Hamburg	14 Nov	17 Apr
Hannover	18 Nov	13 Apr
Helgoland	2 Dec	4 Apr
Kaiserslautern	11 Nov	13 Apr
Kassel	11 Nov	17 Apr
Leipzig (Schkeuditz)	15 Nov	18 Apr
München	1 Nov	2 May
Münster	17 Nov	10 Apr
Nürnberg	10 Nov	17 Apr
Oberursel (Grosser Feldberg)	27 Oct	7 May
Rennerod (Fuchskauten)	27 Oct	4 May
Stuttgart	18 Nov	12 Apr
Szczecin (Stettin), Poland	10 Nov	12 Apr
Trier	22 Nov	6 Apr

Table VII. Number of days between earliest and latest snowfalls, and average number of days with snow on the ground per year for stations in or near East and West Germany (U.S. Dept. of Commerce 1940).

Station	*Number of days between dates of earliest and latest snowfalls*	*Avg number of days with snow on ground*
Berlin (Tempelhof)	147	37.6
Bremen	143	22.5
Brocken	245	152.4
Flensburg	150	31.1
Frankfurt	137	19.2
Hannover	146	22.5
Helgoland	123	7.7
Kaiserslautern	153	20.4
Kassel	157	29.2
München	182	50.8
Münster	144	22.0
Oberursel (Grosser Feldberg)	192	86.3
Rennerod (Fuchskauten)	189	69.9
Szczecin (Stettin), Poland	153	44.3
Trier	135	14.5

Table VIII. Location, elevation and average January air temperature for the stations in and near East and West Germany. Data used in the freezing index and snow condition analysis (U.S. Dept. of Commerce 1966).

Station	*Location North*	*Location East*	*Elev (m)*	*Avg Jan temp (°C)*	*Station*	*Location North*	*Location East*	*Elev (m)*	*Avg Jan temp (°C)*
Berlin (Tempelhof)	52°28′	13°24′	49	–0.6	Kaltennordheim	50°38′	10°09′	494	– 2.6
Bremen	53°05′	08°47′	4	1.0	Kassel	51°19′	09°29′	163	0.1
Brocken	51°48′	10°37′	1152	–4.6	Leipzig (Schkeuditz)	51°25′	12°14′	133	– 0.8
Dresden (Wahnsdorf)	51°07′	13°41′	232	–1.2	Lindenberg	52°13′	14°07′	99	– 1.5
Erfurt (Bindersleben)	50°59′	10°58′	316	–1.6	Magdeburg	52°06′	11°35′	85	– 0.7
Fichtelberg	50°26′	12°57′	1215	–5.7	München	48°09′	11°43′	529	– 2.4
Flensburg	54°46′	09°26′	41	0.6	Münster	51°58′	07°39′	57	1.3
Frankfurt	50°07′	08°40′	109	1.3	Neustrelitz	53°21′	13°05′	70	– 1.3
Freiburg	48°01′	07°50′	245	1.1	Nürnberg	49°29′	11°04′	312	– 1.4
Friedrichshafen	47°39′	09°29′	407	–0.8	Oberursel (Grosser Feldberg)	50°13′	08°27′	801	– 3.2
Gorlitz	51°10′	14°57′	238	–2.0	Potsdam	52°23′	13°04′	85	– 1.1
Greifswald	54°06′	13°27′	3	–1.0	Rennerod (Fuchskauten)	50°40′	08°03′	636	– 2.3
Hamburg	53°38′	09°59′	16	0.0	Stuttgart	48°50′	09°12′	315	0.0
Hannover	52°28′	09°42′	54	0.1	Szczecin (Stettin), Poland	53°24′	14°38′	1	– 0.8
Helgoland	54°11′	07°55′	47	1.8	Trier	49°45′	06°39′	273	1.2
Kaiserslautern	49°27′	07°46′	244	0.4	Zugspitze	47°25′	10°59′	2962	–11.6

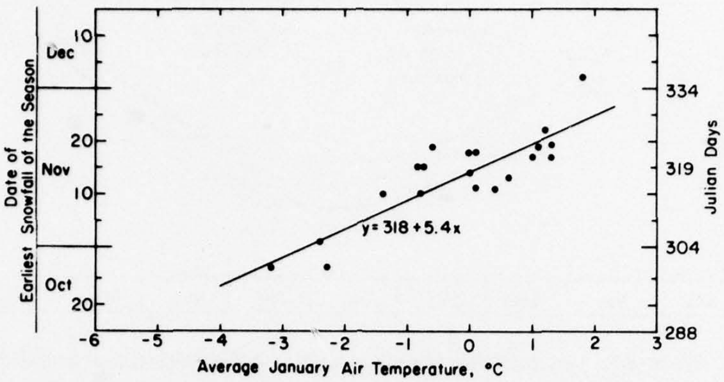


Figure 9. Relationship between the date of earliest snowfall of the season and the average January air temperature for stations in East and West Germany.

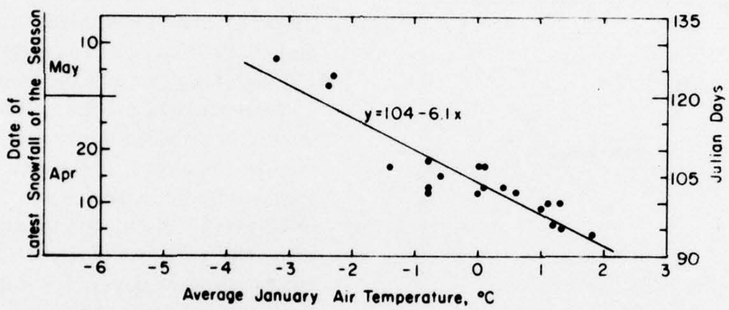


Figure 10. Relationship between the date of latest snowfall of the season and the average January air temperature for stations in East and West Germany.

It would appear that some inconsistencies exist in the starting and ending dates of the freezing season shown in Figure 6 and the earliest and latest snowfall dates presented in Figures 9 and 10. For example, an AJAT value of −2°C shows the freezing season extending from mid-December to early March (Fig. 6), whereas the equations in Figures 9 and 10 indicate that, for an AJAT of −2°C, snowfalls can occur during early November and in late April. This difference can be partially explained by examination of the mean daily minimum air temperature curves for Berlin, Frankfurt, Hamburg, Nürnberg, and München (Fig. 11). The dates of the earliest and latest snowfalls for these stations (Table VI) are also shown on the curves in Figure 11. Note that in all cases the date of the snowfall event on the curves intersects at minimum temperature values of between +1.0 and +3.0°C for earliest snowfalls, and +3.5 to +5.0°C for latest snowfall events. The fact that precipitation in the form of snow occurs when the surface air temperature is above freezing is not uncommon, as was shown in a study by Bilello (1971). Including frozen precipitation data from 11 locations in northeast U.S. and southeast Canada, the study showed that numerous snow or snow showers are observed at air temperatures of between +0.6 and +3.5°C. This information shows that 1) near or slightly above-freezing minimum air temperatures occur much earlier and later in the winter season than is indicated by the start and end of the freezing season, and 2) periods of snowfall can occur when the surface air temperature is slightly above the freezing point. These conditions would also explain the snowfalls reported at those stations with AJAT's of above 0°C in Figures 9 and 10. It is also apparent that the snow amounts due to early or late snowfalls at these warm locations probably remain on the ground for extremely short periods of time and are, therefore, not significant.

It follows, then, to investigate the relationship between the number of days from earliest to latest snowfalls of the season and the average number of days with

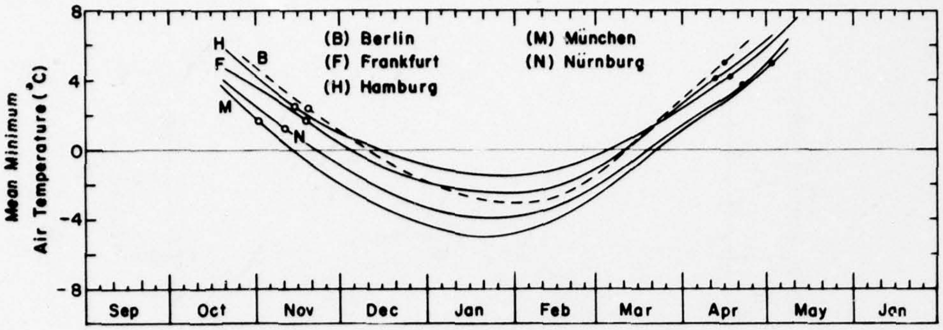


Figure 11. Minimum air temperature curves for stations in Germany (open dots denote the average date of the earliest snowfall of the season and closed dots the average date of the latest snowfall of the season).

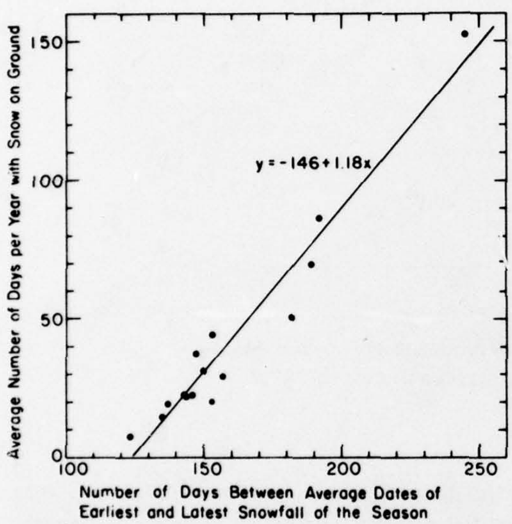


Figure 12. Relationship between the number of days between the dates of earliest and latest snowfalls of the season and the average number of days with snow on the ground in Germany.

snow on the ground (SOG) per year (Table VII). The results for 14 stations in Germany and one in western Poland (Szczecin) are shown in Figure 12. The correlation coefficient in this relationship was $r = 0.89$ and the standard error of estimate of y (average number of days per year with SOG) was ±9.2 days. The regression lines in Figures 10-12 show that, although a warm location like the island of Helgoland (AJAT = +1.8°C) may experience some snow in early December and as late as April, the average number of days with observed SOG throughout the winter is less than eight days (or about 6% of the snowfall season). On the other hand, in a colder location such as Brocken (AJAT = −4.6°C) the maximum snowfall season could extend over a period of 245 days, and an average SOG season lasts 152 days (or about 62% of the snowfall season).

An estimate of the SOG portion of the snowfall season can be provided by the period of time defined as the freezing season. For example, the average freezing season at Berlin extends from 1 January to 11 February or 42 days (Table II), and the average number of days with SOG is 38 days (Table VII). It is likely then that most of these 38 days occur within the time frame defined by the freezing season. Exceptions to this general rule would be at stations with deep snow cover, where the snowpack remains on the ground into a portion of the melt season in the spring and, of course, at warm locations where an average temperature of less than 0°C is not recorded during any winter month. However, in the latter cases, it is probable that most of the snow that remains on the ground for even short periods of time would be likely to occur during the month when the lowest average air temperature is observed.

An attempt was made to see if the AJAT at each station could be used to estimate the average number of days with SOG. For stations located at an elevation of less than 600 m, the correlation coefficient for these parameters was not as good as that found in Figure 12, but the results are reasonable (Fig. 13). Twelve of the 15 stations listed in Table VII were used in the analysis shown in Figure 13. The other three stations in Table VII (Brocken, Oberursel, and Rennerod) are at elevations greater than 600 m, and, as shown in the following paragraph, were treated separately. The correlation coefficient for the relationship shown in Figure 13 was $r = 0.73$, and the standard error of estimate of y was ±5 days. The regression equation was

$$y = 30.1 - 9.8x \qquad (9)$$

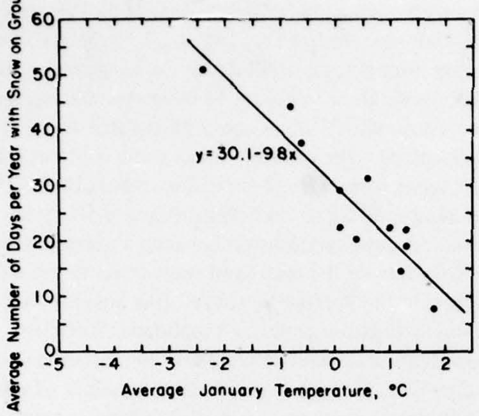


Figure 13. Relationship between average January temperature and average number of days with snow on the ground for 12 stations with elevations below 600 m in or near East and West Germany.

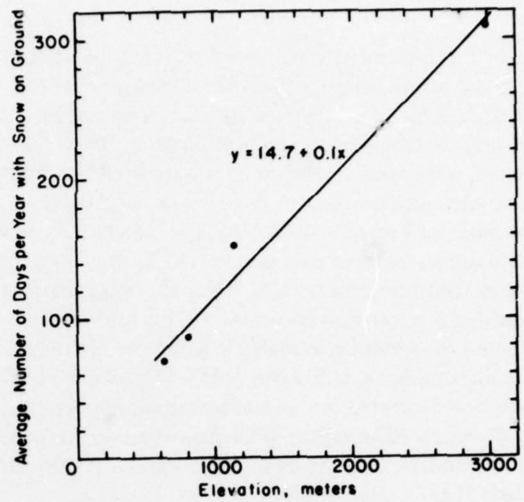


Figure 14. Relationship between station elevation and average number of days with snow on the ground for 4 stations with elevations greater than 600 m in Germany.

where y is the number of days with SOG and x the AJAT (°C). This equation gives SOG values ranging from 10 days per year for an AJAT of +2°C to about 50 days for an AJAT of −2°C.

Use of the AJAT to determine the average number of days with SOG at higher elevations did not prove useful. Consequently, the association between the station's elevation (in meters) and the dependent variable (y) was investigated. SOG data for only four stations at higher elevations in Germany were available. These are the above three stations which were not used in Figure 13, and a fourth, Zugspitze (elevation 2962 m), where an average number of days with SOG of 308 is reported (U.S. Dept. of Commerce 1940). The results of the analysis on these limited data are shown in Figure 14. Although the correlation coefficient derived from the relationship was high (r = 0.96), the standard error of estimate for y was rather large (±18 days). Nevertheless, considering the fact that so little snow information is available for mountainous regions in Germany, any method that provides such data is useful. The regression line in Figure 14, therefore, indicates that regions in Germany that are 1000 m above sea level experience an average of about 110 days with SOG per year, regions at 2000 m about 210 days, and regions at 3000 m about 310 per year.

An interesting point regarding the average number of days with SOG at Zugspitze (i.e. 308 days) should be made here. Note that the length of the freezing season at Zugspitze is 262 days and starts on or about 21 September (Table II). Assuming that an average snow cover also begins to accumulate on that date, then the snowpack would not be completely melted 262 days later (on 9 June), but instead would probably last much longer (i.e. about 300 days or toward the end of July as indicated in Fig. 14). Returning then to a statement made earlier in this report, it appears that a thawing degree-day curve for Zugspitze similar to those shown in Figure 1 for other stations would be useful to help determine the approximate number of thawing degree-days required to ablate snowpacks at higher elevations. Of course, the depth of the snow cover varies greatly from place to place and year to year, so that the amount of heat required to clear the ground of snow each year would differ. Many other meteorological and physical conditions, such as radiation, wind, exposure, precipitation, slope, orientation, etc., naturally contribute to the snowmelt process. Since the problem, however, is essentially hydrologic in nature, it is beyond the scope of this report.

It suffices here to discuss one applicable report on the subject of mountain snowmelt by Hendricks and DeAngelis (1976). They found that two geographic parameters, elevation and latitude, accounted for much of the spatial variation of temperature and precipitation over New England during the winter and spring season. They further state that since temperature controls the amount of precipitation that falls as snow and is highly

related to snowmelt, a spatial and seasonal climatology of snow accumulation, snowmelt and water input can be derived by modeling the effects of elevation and latitude on temperature and precipitation. Their model, which was developed for a watershed in northern Vermont, enables much of the climatic and 10-day synoptic information on snowpack accumulation, snowmelt and water input over unobserved watersheds to be estimated from ordinary U.S. Weather Service temperature and precipitation observations. Further information on the subject is available in a number of published bibliographies, e.g. U.S. Army (1951-78) and Keeler (1971). Additional information on late season snow conditions in the Rhine River region of Germany and the highlands of central Germany can be found in Church (1958) and Flach (1951), respectively.

Inclusion of many other aspects of the snowfall and snow cover such as snowfall amounts, snow depths, and snow-cover density would be beneficial to this study. Unfortunately, these types of basic data, even for representative locations across East and West Germany, were not found in the available sources. Without this information, investigation of the relationship of these snow characteristics with climatic parameters was not possible. However an example of one pertinent study for the United States is that of Beschta (1975), in which a method for estimating snowfall amounts is investigated. Using long-term data from stations in six areas of the United States, Beschta developed regression equations relating a "snowfall index" parameter and air temperature. The snowfall index was defined as the ratio of snowfall depth to precipitation. The study developed equations which provide estimates of the mean monthly snowfall amounts for nearly 200 stations by using air temperature and total precipitation data. An approach similar to the one used by Beschta could be tested for use in Germany. However, sufficient data on snowfall amounts recorded in Germany would be required to either verify the equations developed for the U.S. stations or to establish new ones that may be more applicable to the snow and climatic conditions in Germany.

Studies on the snow depths in Germany at certain locations such as Württemberg (Dieckmann 1936) and Bad Tolz (Brezowsky 1958) have been conducted. In the latter study, snow-depth measurements for 1929 to 1957 were statistically analyzed to determine whether singularities in winter conditions observed in the lowland also occur at higher elevations. The analysis of the Bad Tolz data shows that winter begins during the first 10 days of December and ends in the last 10 days of March. This, incidentally, coincides closely with the starting and ending dates of the freezing season estimated for Bad Tolz (AJAT = −3.3°C) using the relationship given in Figure 6. The Brezowsky study also states that the mean number of days with snow cover at Bad Tolz is 18 in December, 24 in January, 28 in February, and 13 in March, for an average annual total of 83 days. For comparison, the relationship given in Figure 14 estimates the average annual days with SOG as about 86 for Bad Tolz (716-m elevation). The monthly mean snow depth at Bad Tolz varies from 0 to 33 cm in December, 10-55 cm in January, 40-65 cm in February, and 0-40 cm in March. A close relationship between air temperature deviations from the mean and snow-cover depth also appears in the Brezowsky study. It is possible that the same investigation could be expanded if sufficient snow-depth data were available for numerous stations in Germany. Though a comprehensive study of snow conditions in northern Germany has been conducted (Lachmann and Schwalbe 1916) it is now somewhat dated. A similar modern study would provide valuable information for an analysis of the relationship between air temperature and snow depth.

The water content and density of the snow cover is also important, especially in regard to hydrologic investigations. Rachner (1964) analyzed snow-density measurements made during the 1960-61 and 1962-63 winters in the Schierke/Harz region of Germany, and discussed the significance of the measurements for the prediction of water supply from the melting snow. In an older study, Schreiber (1904) investigated the water content and density of the snow cover at elevations ranging from 850 to 1213 m in the Fichtelberg region of Germany. He found the density of the top 0.5 m of undisturbed snow to range from 0.28 to 0.38 g/cm^3 and the density of the 0.5-1.0-m layer to range from 0.34 to 0.39 g/cm^3; the mean density for the layer from 1.0 to 1.5 m in depth was found to be 0.41 g/cm^3. A study of the regional distribution of snow-cover density throughout Germany would provide information on the rate and depth of penetration of ground frost and help solve problems of snow removal and control.

An analysis of snow-cover observations made during November through March at stations in Alaska, Canada, and the northern United States (Bilello 1967) showed that the average snow density could be classified in four general regional categories:

1. Category 1 (density 0.20 to 0.23 g/cm^3) including inland stations reporting very light winter winds.
2. Category 2 (0.24 to 0.27 g/cm^3) consisting of stations with moderate winds and winter temperatures.
3. Category 3 (0.28 to 0.30 g/cm^3) including inland and coastal locations with stronger winds (i.e. average monthly windspeeds of 3 to 7 m/s).
4. Category 4 (0.32 to 0.36 g/cm^3) consisting of cold and windy stations in arctic regions.

A nomograph was developed (Bilello 1967) to estimate the average seasonal snow-cover density for locations in the North American Arctic, Subarctic, and north temperate zones. In the nomograph, the average winter air temperature and windspeed are the independent variables. It is possible that an estimate of the seasonal snow cover density in East and West Germany can be obtained by using the results presented in Bilello (1967). The nomograph, however, is not applicable in mountainous regions, where the winter air temperatures and windspeeds are highly variable over short distances.

MAPPING OF AVERAGE JANUARY AIR TEMPERATURES

Since the primary aim of this study was to develop relationships between the average January air temperature, and 1) the length and severity of the winter regime, and 2) certain aspects of seasonal snow conditions, it remained necessary that a detailed AJAT map for East and West Germany be prepared. The complex problem of attempting to adequately represent various snow conditions on a map is described by Espenshade and Schytt (1956) and by UNESCO et al. (1970). As noted in these reports, the presentation of either the quantitative aspects or descriptive conditions of the snowcover on both small scale (1:5,000,000) and medium scale (1:1,000,000) maps is limited by the data available. There is also the problem of whether monthly seasonal frequencies or a number of various snow conditions could or should be shown on one, two, or even many maps. Though use of individual maps may show the clearest representation of separate conditions, it also necessitates that sufficient data be available for each of the conditions being studied in order to have representative coverage. Utilization of the AJAT as a key index in the relationship between these various wintertime conditions makes it possible to solve many of the above mapping problems.

Analysis of observed AJAT data

A review of several sources of climatic records made it possible to compile AJAT data for 129 stations throughout East and West Germany (Tables VIII and IX). The bulk of the information was obtained from the U.S. Department of Commerce (1973), U.S. Air Force (1970-72), and the U.S. Department of Commerce (1966). Data for a few additional stations were obtained from the Great Britain Meteorological Office (1967) and U.S. Air Force (1974). Included in Tables VIII and IX is an alphabetical listing of the station name, its location, station elevation above sea level, and AJAT. Table VIII contains data from the 32 stations used in the analyses given earlier in this report and Table IX, an additional 97 used in the AJAT map.

Almost all of the AJAT values given in Table IX were computed from the mean maximum and mean minimum air temperature recorded at the station. Minor deviations or inconsistencies in the AJAT values were found at a few of the reporting stations. For example, the AJAT value of −2.4°C at Hohen-Peissenberg (Table IX) was found to be too warm in relationship to surrounding stations or stations at corresponding elevations. Closer examination of the source of the data (U.S. Department of Commerce 1966) revealed that the air temperature measurements at that station were taken at 0700, 1400, and 2100 hours daily. Omission of observations between 2100 and 0700 hours would bias the AJAT and cause it to be too warm. As shown later in this section, a more realistic AJAT value for Hohen-Peissenberg (based on the station's elevation of 983 m) would be approximately −4.1°C. Other small (< 1°C) AJAT adjustments were also necessary for a few stations in Table IX when obvious inconsistencies in this value, due to brief climatic records for the site, were noted.

The relationship between the density of a network of stations and the scale of the map to be used differs with the variability, reliability and distributional nature of the phenomena represented. Espenshade and Schytt (1956) state that a suitable map scale is a matter of judgment and that the selection is related to three factors: 1) the number of stations for which there are data, 2) the sampling errors and other errors inherent in the data, and 3) the steepness of the gradient, i.e. the spacing of the isolines at a given interval.

A thorough evaluation of the above factors, as well as some additional points relative to the AJAT analysis given in this section, indicated that a working map scale of 1:1,000,000 for East and West Germany would be most suitable. Although the 129 stations for which AJAT values are available do not provide as good a coverage as one might expect at this scale, the data are very reliable and the distribution throughout the region is uniform. The spacing between stations in the northern half of Germany, where little change in topography occurs, is compensated by the very small variation in the AJAT values in this region. In fact, intervals of 0.5°C were used in this northern region in order to improve the isoline gradient. A major problem with station coverage occurs in the mountainous regions of Germany. Greater detail of the variations in topography at elevations exceeding about 1000 m would require the use of a map scale larger than 1:1,000,000. However, at these elevations there are fewer stations

Table IX. Location, elevation and average January air temperatures for 95 stations in East and West Germany.

Station	Location (lat)	Location (long)	Elev (m)	Avg Jan air temp (°C)	Station	Location (lat)	Location (long)	Elev (m)	Avg Jan air temp (°C)
Ahlhorn	52°53′	08°13′	48	+0.8	Laarbruch	51°36′	06°08′	32	+1.7
Augsburg	48°23′	10°51′	499	−1.9	Lahr	48°22′	07°49′	155	+0.6
Bad Tölz	47°46′	11°36′	716	−3.3	Landsberg	48°04′	10°54′	623	−3.1
Bamberg	49°53′	10°52′	386	−1.1	Lechfeld	48°11′	10°52′	554	−2.3
Bayreuth	49°58′	11°34′	361	−1.7	Leck	54°47′	08°56′	7	0.0
Berlin (Tegel)	52°33′	13°18′	46	−0.8	Leipheim	48°26′	10°14′	477	−1.7
Bitburg	49°58′	06°33′	374	−0.6	Leipzig	51°19′	12°25′	148	−1.1
Boehmer (AAF)	49°36′	07°11′	331	−0.6	Mannheim (Sandhofen)	49°34′	08°28′	96	+0.8
Boizenburg-Elbe	53°23′	10°43′	46	0.0	Memmingen	47°59′	10°13′	634	−2.3
Bremgarten	47°54′	07°35′	213	+1.1	München (Neubiberg)	48°04′	11°38′	551	−2.2
Bruggen	51°12′	06°08′	73	+1.8	Neuberg	48°42′	11°12′	380	−1.9
Buchel	50°10′	07°03′	477	−1.4	Nordholz	53°46′	08°39′	23	+0.6
Celle	52°35′	10°01′	39	+0.3	Norvenich	50°49′	06°39′	117	+1.6
Cottbus	51°47′	14°19′	71	−1.1	Nürburg	50°21′	06°57′	629	−2.8
Darmstadt	49°51′	08°40′	281	0.0	Ohringen	49°12′	09°31′	256	+0.6
Diepholz	52°35′	08°20′	39	+0.8	Oldenburg	53°10′	08°10′	11	+0.8
Düsseldorf	51°16′	06°45′	41	+1.6	Passau	48°35′	13°29′	408	−1.9
Echterdingen	48°41′	09°12′	401	−0.5	Pferdsfeld	49°51′	07°36′	396	−1.1
Eggebek	54°37′	09°20′	20	0.0	Plauen	50°30′	12°09′	408	−2.6
Emden	53°22′	07°13′	1	+0.8	Regensburg	49°02′	12°04′	339	−1.9
Erding	48°18′	11°54′	460	−1.7	Rhein-Main	50°02′	08°35′	112	+0.3
Essen	51°25′	06°57′	128	+1.6	Saarbrucken	49°13′	07°01′	191	+1.2
Fassberg	52°55′	10°11′	75	+0.3	Schleswig	54°27′	09°30′	22	0.0
Frankfurt-Oder	52°21′	14°32′	58	−1.3	Schönfeld (Berlin)	52°20′	13°31′	54	−0.6
Fulda (AAF)	50°32′	09°39′	308	−1.7	Sembach	49°30′	07°52′	321	−0.6
Gardelegen	52°31′	11°24′	48	0.0	Siegenburg	48°45′	11°48′	404	−2.2
Garmisch	47°30′	11°06′	708	−2.8	Sollingen	48°46′	08°04′	123	+0.8
Gatow	52°28′	13°08′	49	−0.8	Sonneberg	50°23′	11°11′	630	−3.3
Geilenkirchen	50°57′	06°02′	87	+1.9	Spangdahlem (AB)	49°58′	06°42′	368	−0.6
Geisenheim	49°59′	07°58′	108	+1.1	Stotten-Göppingen (AAF)	48°40′	09°52′	736	−2.6
Giebelstadt	49°38′	09°57′	300	0.0	Sylt	54°54′	08°20′	16	+0.8
Giessen	50°36′	08°44′	152	+0.3	Teterow	53°46′	12°37′	50	−0.3
Grosser Falkenstein	49°05′	13°17′	1308	−5.3	Ueckemunde	53°45′	14°04′	7	−1.1
Grosser Inselsberg	50°51′	10°28′	920	−4.4	Ulm	48°24′	09°59′	482	−1.7
Gütersloh Raf	51°56′	08°19′	21	+1.1	Warnemunde	54°11′	12°05′	13	+0.3
Hahn	49°56′	07°15′	503	−1.8	Wasserkuppe	50°30′	09°57′	925	−3.6
Halle-Krollwitz	51°31′	11°57′	115	−0.8	Weiden	49°41′	12°11′	402	−2.7
Hof	50°19′	11°55′	568	−2.8	Weimar	50°59′	11°19′	268	−1.4
Hohenfels	49°13′	11°50′	442	−3.1	Weissenburg	49°02′	10°58′	435	−2.2
Hohen-Peissenberg*	47°48′	11°01′	983	−4.1	Wertheim	49°45′	09°30′	338	−0.3
Hopsten	52°23′	07°36′	39	+1.6	Wiesbaden	50°05′	08°14′	140	+0.3
Husum	54°31′	09°08′	28	+0.3	Wildenrath	51°06′	06°13′	89	+1.9
Illesheim	49°28′	10°23′	325	−0.8	Wismar	53°54′	11°27′	30	0.0
Ingolstadt (Manching)	48°43′	11°31′	370	−2.2	Wittenberg	51°53′	12°39′	109	−1.1
Jever	53°34′	07°53′	6	+0.6	Wittenberge	53°00′	11°48′	26	−0.3
Karl-Marx-Stadt	50°49′	12°54′	382	−1.9	Wittmundhaven	53°35′	07°40′	8	+0.6
Karlsruhe	49°01′	08°23′	116	+0.8	Wurzburg	49°48′	09°54′	260	0.0
Köln-Bonn	50°51′	07°08′	91	+1.3	Zweibrucken	49°15′	07°24′	343	0.0
Köln-Butzweilerhof	50°58′	06°54′	49	+1.6					

** Observations taken only at 0700, 1400 and 2100 hours; reported average January air temperature (−2.4°C) is therefore too warm. Estimated value of AJAT of −4.1°C was used.*

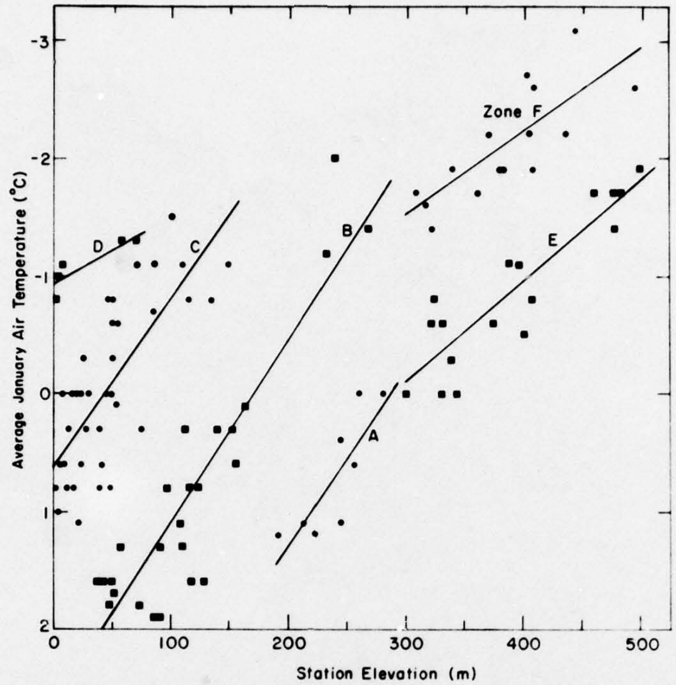


Figure 15. Relationship between AJAT and elevation separated regionally by zones in Germany.

making air temperature measurements on a regular basis, so that data coverage for a map scale of 1:500,000 would be insufficient. At elevations above 1000 m, the problem becomes more acute because of the marked increase in the steepness of the AJAT gradient. This is caused by the rapid increase in topography over short distances at these elevations. Intervals of 1°C for AJAT values from −1.0 to −5.0°C on the 1:1,000,000 map were satisfactory. However, beyond −5.0°C, the scarcity of data and the steepness of the AJAT gradient made it necessary to increase the interval on the map to 5°C. The resultant map* showing these AJAT isolines and a discussion on the analysis conducted in developing the map follows.

Since the most important single value of this entire study was the AJAT, it became obvious that a comprehensive investigation on the relationship between the AJAT and altitude variations and regional differences needed to be conducted.

The necessary data for evaluating the relationship between AJAT and altitude is given in Tables VIII and IX. Examination of the elevation values showed that 107 of the listed stations are located at an altitude of less than 500 m. In plotting this many sets of data, expanded scales of the two variables were needed to more clearly define the relationship. The results are shown in Figure 15. Initially, the widely scattered points acquired in the analysis seemed to indicate that a useful relationship did not exist between the variables. Consequently the 107 AJAT values were then plotted on a map of Germany to determine if variations in the data could be regionally identified. This particular approach made it possible to group the locations of the AJAT values on a regional basis, and then associate the geographical zones with the AJAT's as shown in Figure 15. Some striking patterns of consistency evolved from this analysis. A principal separation of the points shown in Figure 15 occurred between stations located above and below 300-m elevation. Although it appears that most of the points above 300 m could easily be an extension of many of the points below this value, the slope of line of best fit changed sufficiently to warrant the separation. As will be shown later, the slope of the line in this relationship decreases even further for stations above 500 m.

Further investigation of the points for stations located between sea level and 300-m elevation showed that warmer sites (zones A and B) were located in the southwest or central parts of Germany, whereas the colder sites (zones C and D) were located in the north or northwest part of the country (Fig. 16). Note that the coldest group of stations (zone D) is farthest from the winter warming influence of Atlantic Ocean Maritime air. None of the stations in this zone record

*** Maps presented in this report have been reduced.**

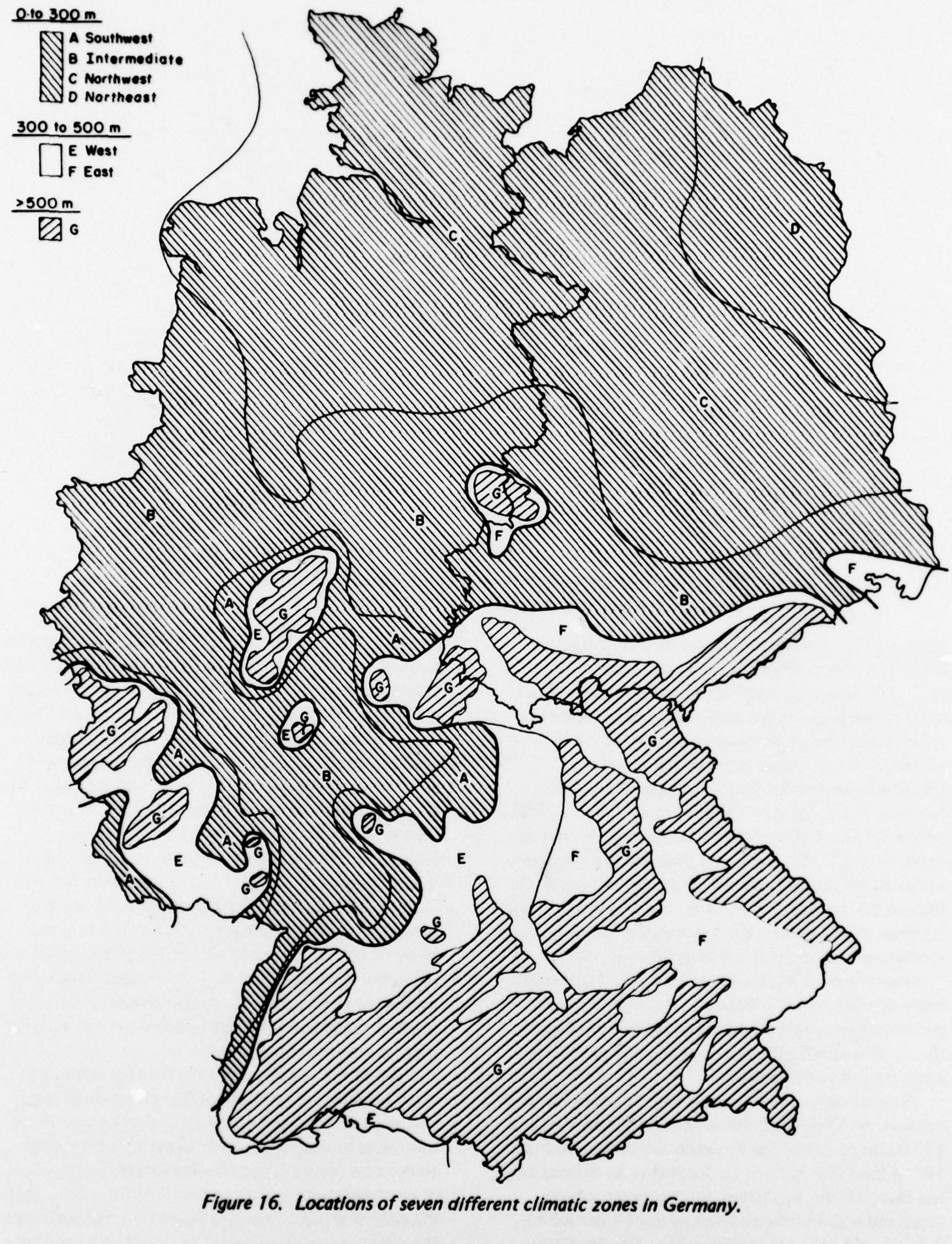


Figure 16. Locations of seven different climatic zones in Germany.

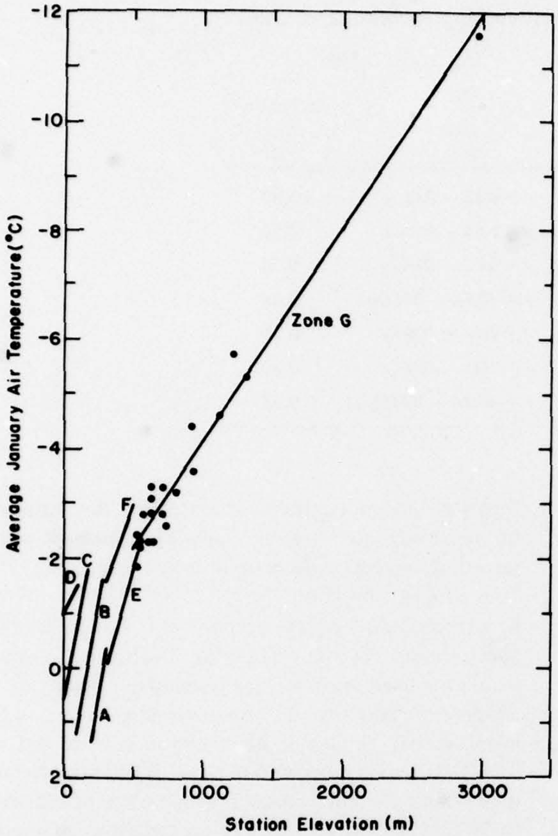


Figure 17. Relationship between AJAT and elevation for stations above 500 m in Germany (zone G). Zones below 500 m were transposed from the analysis shown in Figure 15.

positive AJAT's. The stations in zone C cover a larger portion of land, and only two of the 37 sites included in this group record AJAT values of 1.0°C or more. The stations in Zone B contain the largest range in AJAT values, extending from +1.0 to −2.0°C. Examination of the stations' locations reveals that many of the warm sites in this group are in the Rhine River valley of southwest Germany and all the stations with AJAT's of less than 1.0°C are at elevations greater than 200 m. In contrast, the stations in zone A record AJAT's of 0°C or more even though they are located at elevations of between 190 and 290 m. This investigation clearly shows that a useful relationship between AJAT and station elevation can be extracted from the points shown in Figure 15 if a regional separation of the data is employed.

The stations shown in Figure 15 which are located at between 300- and 500-m elevation also displayed a difference in climatic regimes. One group (zone E) recorded AJAT's of between 0°C and −2°C, and a second group (zone F) recorded colder AJAT's of from −1.4 to −3.1°C. Inspection of the regions in Germany where zones E and F are located (Fig. 16) shows that the warmer group of stations is in the southwest portion of the country and the colder stations in the southeastern portion. It is again probable that the stations in zone E are warmer because they are closer to an ocean influence, whereas the stations in zone F experience a continental effect.

Although some subjectiveness in the demarcation of points was required, many of the points that were questionably grouped in Figure 15 were fortunately located near the border of the adjacent zone in question. The sequential overlap helped show that the geographical trend of the interrelationship was at least uniform in direction. Linear regression analyses on the relationship presented in Figure 15 for the groups of stations in zones A-F were conducted. The results of the statistical computations (given in Table X) show that the variables are highly correlated and help to confirm the idea to separate the region into climatically different zones. Physically, these different midwinter climatic zones in Germany are explained in part by variations in latitude, altitude, and proximity to Atlantic and Baltic maritime influences.

The last grouping of the 107 German stations consisted of 20 locations at elevations above 500 m. Since the range in height for these stations extended to almost 3000 m, it was necessary to significantly reduce the scale of the plot for the variables in the relationship between AJAT and elevation. This plot on the reduced scale is shown in Figure 17. No attempt was made to investigate the possibility that climatic zones existed in this group of stations. Two reasons are given for this decision: 1) The data sets were all grouped together, indicating that separation of the data would have required excessive subjectivity, and 2) at elevations above 500 m it is unlikely that near-surface conditions, such as maritime-continental contrasts, winter air temperature inversions, river valley influences, etc., would impart much meaning to a regional variation in the AJAT. Consequently, all stations at 500 m or more above sea level were included in zone G (see Fig. 16). Most of the stations in this group are centered between 500 and 1000 m, and there is a large gap in available information between 1400 and 2900 m. However, the slope of the line of best fit for zone G data does not differ significantly when the isolated station (Zugspitze) is omitted from the group. Note that six other lines are shown between 0 and 500 m on Figure 17. These lines are the regression lines shown on Figure 15 for zones A-F. The lines have been reduced in scale and transferred to Figure 17 to show how they compare with the regression

Table X. Statistics on the linear relationship between the variables shown in Figures 15 and 17.

Figure no.	Zone letter	Number of stations in the zone	Line of best fit	Correlation coefficient (r)
15	A	8	$y = 4.30 - .0151x$	0.83
15	B	25	$y = 2.64 - .0155x$	0.90
15	C	37	$y = 0.62 - .0143x$	0.75
15	D	5	$y = -0.94 - .0056\|x\|$	0.88
15	E	17	$y = 2.48 - .0086x$	0.90
15	F	15	$y = 0.61 - .0071x$	0.79
17	G	20	$y = -0.26 - .00388\|x\|$	0.98

line obtained from the zone G station. This visual comparison shows that the AJAT decreases gradually with elevation, and that data sets disperse as one approaches sea level. This dispersion may be a result of having many more stations available at lower elevations, but it also appears reasonable that the variability in the relationship at the low elevations is due to the climatic variations discussed earlier.

It is of particular interest to find that the decrease in AJAT per hundred meters of altitude in Germany changes gradually from 1.26°C/100 m (between 0 and 300 m) to 0.78°C/100 m (between 300 and 500 m) to 0.39°C/100 (between 500 and 3000 m).

During the time that the analysis of AJAT relationships was being conducted, a similar investigation for portions of Virginia and West Virginia was completed and published by Pielke and Mehring (1977). They present a method for improving the analysis of monthly mean temperatures in mountainous terrain for a limited geographic region. The technique is based on plotting mean monthly temperatures as a function of elevation, fitting the data points with linear regressions and plotting the estimated mean temperatures on a topographic map in place of elevation. Pielke and Mehring (1977) found the decrease in surface temperatures with height between 100 and 1000 m to be ≃ 0.57°C/100 m. This value agrees well (0.57° vs about 0.50°C/100 m) with the results obtained from the German stations between 100 to 1000 m (see Fig. 17). These comparable results from two independent studies and from widely separated regions provide added support in the use of the relationship.

The surface temperature changes with height were also compared with records of the midwinter upper "free air" temperature soundings. These temperature profiles were made in January for 332 radiosonde flights at München, and for an unknown number of flights at Lindenberg (Berry et al. 1945). A summary of these midwinter "free air" lapse rates shows München recording an average decrease in temperature of 0.32°C/100 m (between the surface and ≅ 300 m) and Lindenberg recording an average decrease of 0.31°C/100 m (between the surface and ≃ 3000 m). During the German winter the decrease in surface (ground or station) air temperature and "free air" measurements differs markedly between 0 and 500-m elevation (1.26 and 0.78°C/100 m as compared to 0.32°C/100 m), whereas these values are much closer at an elevation of 500 m (0.39°C vs 0.32°C/100 m). This comparison, of course, is not entirely valid because the radiosonde observations are generally taken twice a day at selected times. The instantaneous temperature value obtained at these times would not give the average temperature for the day. It thus should not be directly compared with the AJAT. However, in both instances the values are summaries of lengthy periods of record, and so the comparisons are based on this long-term concept. At any rate, the comparison was presented as a point of interest and does not enter into the need for continued analysis in this study.

Development of detailed maps

Using the recorded values of the AJAT at 129 stations, plus the altitude and regional relationship presented in Figures 15, 16 and 17, a detailed map showing an areal distribution of the AJAT could be drawn. Since altitude contributes an essential part to the development of such a map, topographic contours which show a reasonable separation of height lines with intervals of about 200 to 300 m were required. After considerable deliberation, it was decided that an original map scale of 1:1,000,000 provided the best spacing for tracing acceptable contour lines. This contour map, therefore, was based on the "Atlas of the World"

(N.Y. Times 1975). (The original map tracing was reduced in size for inclusion in Appendix B.) Intervals of 0 to 100 m, 100 to 200 m, 200 to 500 m, 500 to 1000 m, and > 1000 m were used for a base map. The first three intervals include most of the northern three-quarters of East and West Germany, and except for the extreme southern border, the remainder of the region is included within the 500- to 1000-m interval. The detail provided in this topographic contour map was more than sufficient in view of the number of data points available and the errors of estimate obtained in the AJAT relationships. The locations of the 129 stations for which AJAT values were available (Tables VIII and IX) are also shown in Figure B1. Exact locations of some of these stations were obtained from the Britannica Atlas (1974).

An isoline map of the AJAT for East and West Germany was developed (Fig. B2) by utilizing the following information: 1) the recorded AJAT values for the 129 stations, 2) the relationship between AJAT and elevation (Fig. 15 and 17), 3) the regional difference in the AJAT, and 4) the topographic contour base map (Fig. B1). In the northern half of the region where the AJAT ranges from approximately -2.0 to +1.5°C, an interval of 0.5°C was used to draw the isolines. Along the southern border where the topography is rough and the changes in elevation rapid, the interval was changed to 5.0°C. For the rest of Germany where the AJAT values range from -2.0 to -5.0°C, an interval of 1.0°C was used. Although the above factors were closely considered, an effort to draw smooth lines was made in the analysis of Figure B2. The problem is not serious in those regions where the AJAT gradient is small, e.g. in the region where the spacing interval is 0.5°C, but in mountainous regions, the map scale used is too small to define the frequent changes in elevation, and so the smooth isolines shown in Figure B2 are approximate and should be used with caution. Fortunately, in most cases recorded values of AJAT were observed at stations located near the summit of mountains (e.g. Brocken and Zugspitze) so that the isolines surrounding these stations were a matter of both interpolation and extrapolation. The results show the northern lowlands and Rhine River valley regions of Germany experiencing AJAT's of above freezing. At the higher elevations of central and western Germany and along the southern East German and southeastern West German borders, the AJAT varies from -1.0 to -5.0°C. Values colder than -5°C occur mostly in the Southern Alpine regions of West Germany at elevations of approximately greater than 1200 m.

Since this entire study is principally based on the AJAT, the main purpose for Figure B2 is to provide a user with a reasonable estimate of that value for any general region in Germany. It should be accepted that the map cannot provide exact values at specific points, especially, for example, within heavily forested areas or extremely windy locations. However, based on the observed data and the statistical analysis, AJAT values, except for mountainous or alpine regions, can be obtained with confidence from the map.

A series of mean monthly air temperature maps also appear in a climatic atlas of Europe, published by the World Meteorological Organization (WMO-UNESCO 1970). However, the temperature maps presented in that atlas for January are much smaller than those used in this study, and they provide temperature isoline intervals of > 2.5°C as compared to the > 0.5°C intervals given in Figure B2. The isoline analyses on the two maps were nevertheless matched for comparison purposes and showed good agreement. The lack of detail and the large intervals between the temperature isolines precluded any consideration of using the WMO Atlas for this study.

The isoline map (Fig. B2) would be especially useful for planning midwinter cross-country activity. Knowledge of the distribution of the AJAT throughout East and West Germany would provide essential information on the probable length and severity of the winter and some information on average snow conditions. These data are important in wintertime activities such as: 1) overland movement of men and machines, 2) winter construction of roads and runways at remote sites, 3) preparation for bivouac or tactical maneuvers, 4) the preselection of staging or storage areas, and 5) the location and installation of field communication equipment. A historical account of the types of crucial winter problems that can develop in snow-susceptible regions is described in the following quote from MacDonald (1973) concerning the movement of American troops near Ardennes in January 1945:

> The terrain and the weather were the big obstacles. Whenever the tanks found fairly level terrain, they could move cross-country over the frozen ground with some facility, but more often than not, the ground was hilly, wooded or marshy, confining the tanks to the icy roads. In advancing up a steep hill on 5 January, eight tanks of a task force of the 2nd Armored Division stalled in a row on the ice. The antitank guns of the 84th Division and their prime movers skidded, jackknifed, collided, and effectively blocked a road for several hours. Two trucks towing 105 mm howitzers skidded and plunged off a cliff.

Although the results of this study are not intended to provide better day-to-day weather forecasts, the results define those areas in Germany that are potentially

susceptible to freezing temperatures, and can be used to evaluate the time of occurrence and intensity of winter problems associated with snow, ice, and frozen ground.

APPLICATION AND DISCUSSION

As noted in the *Introduction*, much of the incentive for conducting the study was due to the frequent requests for climatic information on wintertime conditions in remote regions in West Germany. The inquiries were generally associated with problems of frost action on pavements and runways, freezing index information for construction requirements, or freezing precipitation data in preparation for plans and development of methods for snow and ice control.

Examples

In order to describe how the numerous relationships presented in this report can be used, a list of typical winter-associated inquiries is provided, and procedures followed to obtain approximate answers to the questions are explained. As an example, assume that construction of a civilian or military installation is planned in the vicinity of 47°55'N latitude and 12°40'E longitude in West Germany, and the following information on the winter regime is required:

1) Mean freezing index (MFI) value.

2) Average length of the freezing season.

3) Approximate dates of the start and end of the freezing season.

4) Approximate dates of the earliest and latest snowfalls of the season.

5) Average number of days with snow on the ground per season.

Such data are often required to determine depth of frost penetration for foundation purposes, and in decisions on building orientation or design for snow or ice removal and control. Using the given coordinates, the average January air temperature (AJAT) for the example location is about −2.8°C as obtained from the analysis shown in Figure B2. Another, and perhaps more precise, way to determine the AJAT is to first refer to a topographic map similar to that shown in Figure B1 and obtain the elevation (in meters above sea level) of the location. In this case, the elevation is estimated to be about 600 m. Acquisition of exact elevations will provide, in this case, more accurate AJAT values and should be obtained when possible. Referring then to the climatic zone map prepared in this study (Fig. 16), the locality in question is in zone G, i.e. the zone in which all stations are above 500-m elevation. Continuing on to Figure 17, we find that for stations in zone G at an elevation of 600 m the AJAT is near −2.6°C. The two values, of course, do not exactly agree because of the deviations obtained in the linear regression analysis shown in Figure 17 and the minor inaccuracies obtained by using even spacing for the temperature isolines drawn in Figure B2.

Assuming the representative AJAT value is an average of the two methods (or −2.7°C), then the relationship given in Figure 4, line A, shows that the MFI is about −185 (base 0°C). For those more familiar with English units this MFI is equivalent to 333 (base 32°F). If a corresponding design freezing index (average of 3 coldest years in a 30-year period) is required, it can be derived from a relationship given in a U.S. Army (1965) technical manual. This manual also provides estimates on the depth of frost penetration in certain soils under certain conditions through the use of freezing indices. This and similar manuals (e.g. U.S. Army and Air Force 1966b) and other related publications on the subject (e.g. Quinn and Lobacz 1962, and Sanger 1968) should be reviewed to appreciate the full potential of the MFI.

An estimate of the average length of the freezing season for the area under investigation is given in Figure 5. The diagram shows that for an AJAT of −2.7°C one can expect about 90 days during the winter season when the average daily air temperatures are at or below 0°C. From the relationships shown in Figure 6, lines A and B, one finds that for an AJAT of −2.7°C the freezing season would on the average begin around early December, and end in early March. Of course, daily, weekly, and monthly fluctuations in air temperature often result in early or late season frost days and/or midwinter temperature thaws.

Information on probable earliest and latest dates of snowfall occurrence is obtained from the analysis given in Figures 9 and 10. Again, for an AJAT of −2.7°C these diagrams show that an earliest snowfall greater than a trace can occur around 1 November and a latest snowfall around 30 April. An estimate of the average number of days with snow on the ground for the area in question can be obtained by using three different parameters as the independent variable. Use of the length of time (181 days) between the above estimated maximum dates of earliest and latest snowfall (1 November to 30 April) in the relationship given in Figure 12 provides an average annual number of days with snow on the ground (SOG) of about 68 days. In Figure 13, the AJAT of −2.7°C indicates the area will record about 57 days of SOG each year and in Figure 14, the assumed elevation of 600 m for the site under consideration reveals an average of about 75 days with SOG per year. Although no attempt was made to determine

which of these three values is statistically more valid, note that the latter two estimates (57 and 75 days) were taken from near the limits of the applicable range of the regression lines given in Figures 13 and 14. Consequently, they may not be as representative as the first value which was taken from near the midpoint of the regression line shown in Figure 12.

The preceding exercises were conducted to show how a potential user would utilize the material presented in this study. The example given applies to one location in West Germany experiencing a particular winter regime based on geographical location and elevation. Similar applications of the information included in this paper make it possible to evaluate certain cold season conditions for any location in East or West Germany.

It should be stressed that the estimated values obtained from this study represent average conditions of the winter regime. The results are not meant to provide probabilities or predictions of climatological or meteorological extremes of temperature or snowfall events. For example, the AJAT for Kaiserslautern is +0.4°C (Table VIII), which indicates that the location experiences only sporadic periods of freezing air temperatures. However, heavy snows on 19 and 20 March 1975 severely damaged many trees in the Hochspeyer State Forest near Kaiserslautern and required an extensive trimming and clearing project by U.S. Army and community personnel (*Soldiers* 1975). Although such snowstorms apparently occur infrequently at this location, the information given in Table VI shows that a snowfall at Kaiserslautern has been observed as late as 13 April. Early and late season snowstorms are commonly reported at widely scattered locations every winter, such as the one that spread over parts of northern New England and New York on 19-20 May 1977 (Ludlum 1977). Such random storms are difficult to predict on a short-term basis, and are almost impossible to forecast on a long-range basis.

Aircraft and satellite imagery to determine the areal extent of the snow cover has recently become a useful operational and analytical tool, and could become useful in snowfall prediction. Discussion of the subject and presentation of the LANDSAT photographs of snow cover in West Germany are given in Appendix A.

Influence of vegetation

In addition to location and elevation, another major factor that must be considered in a study of areal distribution of snow on the ground is the influence of the vegetative cover. Adams (1976) cites and briefly reviews studies on this subject and presents results of snow-cover data that he obtained in the vicinity of Peterborough, Ontario, Canada. Adams found that in the area studied, the vegetationally based zones are generally most distinct with regard to the water equivalent of the snow cover. However, Adams also states that "although useful working relationships have been established between snow cover and landscape types within distinctive climatic regions, extrapolation of these relationships to other regimes or even to relatively extreme climatic years within a given region must be undertaken with caution." Küchler (1967) makes reference to a vegetation map of Germany at a scale of 1:1,000,000 prepared in 1943 by Hueck. Küchler notes that Hueck adapted his information on vegetation in a manner which properly uses the available map space to capacity. Use of the data given on this vegetation map would be useful in determining variations in snowfall amounts in certain regions.

Incidentally, Swanson (1970) found that under a continuous tree canopy of a vast timbered area (such as in the Forest Reserves of Alberta, Canada) differences in slope, aspect, elevation, and crown closure were not important in determining snow distribution and accumulation. It is suggested, therefore, that general management guidelines could be drawn up for managing snow accumulation in such forested areas without regard to topographic variables. In contrast, however, Caine (1975) used records obtained from 24 snow courses in the San Juan Mountains of Southwest Colorado to show that the variability of seasonal peaks of snow accumulation is inversely related to elevation. The fact that all of the snow courses used in this analysis were below the treeline indicates that some contradiction exists between these and Swanson's results. In conclusion, therefore, it seems appropriate to repeat the statements made by McKay and Thompson (1972) on the problems associated with the mapping of snowfall and snow cover in North America. They note that "....because of the natural variability of snowfall and snow cover, the interpretation for point to area values remains a major problem for the cartographer. The use of zonation and height-dependency curves is recommended to improve the quality of maps." With this suggestion in mind, it is hoped that the investigations conducted in this report provide the type of approach and information needed to achieve some of these mapping requirements.

LITERATURE CITED

Adams, W.P. (1976) Areal differentiation of snow cover in East Central Ontario. *Water Resources Research*, vol. 12, no. 6, p. 1226-1234.

Alföldi, T.T. (1976) Digital analysis of Landsat MSS imagery for snow mapping applications. Report, Canadian Centre for Remote Sensing.

Anderson, D.M., H.L. McKim, L.W. Gatto, R.K. Haugen, W.K. Crowder, C.W. Slaughter and T.L. Marlar (1974) Arctic and subarctic environmental analysis utilizing ERTS-1 imagery, Type III. Final Report to NASA for the period June 1972-February 1974, Contract no. S-70253-AG.

Antonik, B. (1961) The climate of Potsdam. III: Snow cover, snow density, and snowfall in Potsdam (text in German). *Abhandl. Meteorol. Hydrol. Dienstes der DDR*, vol. 8, no. 61, p. 1-64.

Antonik, B. and W. Boer (1962) The portion of snow in the precipitation in the region of the German Democratic Republic (text in German with English abstract). *Z. Meteorol.*, vol. 16, no. 9-10, p. 231-239.

Barnes, J.C. and C.J. Bowley (1970) The use of environmental satellite data for mapping annual snow-extent decrease in the western United States. Final report prepared for Dept. of Commerce, Environmental Science Services Administration.

Barnes, J.C. and C.J. Bowley (1974) Handbook of techniques for satellite snow mapping. Environmental Research and Technology, Inc., Concord, Mass., ERTS Document No. 0407-A.

Bekker, M.G. and R.F. Legget (1947) Snow studies in Germany. Directorate of Vehicle Development, Dept. of National Defence (Army), Ottawa, Canada.

Berry, F.A., E. Bolloy and N.R. Beers (1945) *Handbook of meteorology*. New York: McGraw-Hill Book Company, Inc.

Beschta, R.L. (1975) A method for estimating snowfall amounts. *Water Resources Bulletin* (American Water Resources Association) vol. 11, no. 6.

Bilello, M.A. (1967) Relationships between climate and regional variations in snow-cover density in North America. *Physics of Snow and Ice, Proceedings of the International Conference on Low Temperature Science*, 1966, vol. 1, pt. 2.

Bilello, M.A. (1971) Frozen precipitation: Its frequency and associated temperatures. *Proceedings, Eastern Snow Conference, Fredericton, New Brunswick, Canada.*

Bilello, M.A., R.E. Bates and J. Riley (1972) Mesoscale measurement of snow-cover properties. *Proceedings, International Symposia on Role of Snow and Ice in Hydrology*, Banff, Canada.

Birkner, O. (1890) Snow-cover duration in the Erz Mountains of Saxony (text in German). *Meteorologische Z.*, vol. 7, p. 201-205.

Boyd, D.W. (1976) Normal freezing and thawing degree-days from normal monthly temperatures. *Canadian Geotechnical Journal*, vol. 13, no. 176, p. 176-180.

Brezowsky, H. (1958) Certain results of snow depth measurements at Bad Tolz (text in German). *Meteorologische Rundschau*, vol. 11, no. 1, p. 30-32.

Britannica atlas (1974) Chicago: Encyclopedia Britannica, Inc.

Brose, K. (1952) On snow conditions of the last 50-60 years in central and southern West Germany (text in German). *Ber. deut. Wetterdienstes U.S. Zone*, vol. 6, no. 38, p. 171-177.

Bunting, J. and D. Lamb (1968) Heavy snow in the Chicago area as revealed by satellite pictures. Satellite and Mesometeorology Research Project, Research Paper no. 75, University of Chicago.

Caine, N. (1975) An elevational control of peak snowpack variability. *Water Resources Bulletin*, vol. 11, no. 3, p. 613-621.

Church, J.E. (1958) Forecasting the summer runoff of the Rhine River. Union Géodésique Geophys. Intern. Assoc. Hydrologie Sci. Assemb. Toronto 1957, vol. 4, p. 97-135.

Clapp, P.F. (1967) Specification of monthly frequency of snow cover based on macroscale parameters. *Journal of Applied Meteorology*, vol. 6, no. 6, p. 1018-1024.

de Borchgrave, A. (1977) Nightmare for NATO. *Newsweek*, 7 February, p. 36-38.

Deutscher Wetterdienst (1953) Climatic atlas of Baden-Württemberg (text in German).

Dieckmann, A. (1929) The annual and monthly percentage of snow in total precipitation (text in German). *Ber. Tätigkeit Preussischen Meteorologischen Inst.*, p. 109-114.

Dieckmann, A. (1930) Snow-cover periods (text in German). *Z. angew. Meteorologie*, vol. 47, p. 171-177.

Dieckmann, A. (1935) Snow cover for winter sports in the Swabian Hills (text in German). *Geograph. Wochenschr*, vol. 3, p. 1079-1082.

Dieckmann, A. (1936) Snow melting (text in German). *Erdgeschichtl. u. landeskundl. Abhandl. Schwaben u. Franken*, no. 18, p. 1-79.

Dietz, G.C. and B. Kolker (1975) A classic lake-effect snowstorm at Buffalo, N.Y. on 15 November 1974. *Weatherwise*, vol. 28, no. 5, p. 205-207.

Eschner, A.R. and H.M. Brechtel (1973) Establishing a snow survey in the State of Hessen, W. Germany. *Proceedings, Eastern Snow Conference*, p. 32-35.

Eschner, A.R., T.M. Lillesand and D.E. Meisner (1977) Satellite remote sensing of snowcover in the Adirondack Mountains. Final Report to NOAA, National Environmental Satellite Service.

Espenshade, E.B. and S.V. Schytt (1956) Problems in mapping snow cover. U.S. Army Snow, Ice and Permafrost Research Establishment Research Report 27.

Flach, E. (1951) Special hydrometeorological characteristics of the central German mid-summer and late winter (text in German). *Abhandl. Meteorologischen Dienstes, DDR*, no. 5, p. 5-56.

Gilman, G.D. (1964) The freezing index in New England. CRREL Special Report 63. AD 603464.

Goddard Space Flight Center (1975) Cumulative non-U.S. standard catalog, Landsat-1 and -2. Goddard Space Flight Center, Greenbelt, Maryland.

Great Britain Meteorological Office (1967) Tables of temperature, relative humidity and precipitation for the world. Part III: Europe and the Atlantic Ocean North of 35°N. Meteorological Office Publication 617c, London.

Greim, G. (1939) Snowfall in Hesse during the years 1902-1930 (text in German). *Reichsamt für Wetterdienst, Wiss. Abhandl.*, vol. 5, no. 8, p. 1-26.

Haase, E. (1966) Considerations of methods for determining the snow line, based on recent snow line determinations in the southern Black Forest (text in German). *Naturforschende Gesellschaft zu Freiburg im Breisgau*, Berichte 56, no. 1, p. 17-22.

Haefner, H., R. Gfeller and K. Seidel (1974) Mapping of snow cover in the Swiss Alps from ERTS-1 imagery. *Earth Survey Problems*, Berlin: Akademie Verlag, p. 351-355.

Haeuser, J. (1933) The depth and water content of new snow covers. The yield and duration of heavy snowfalls in

Munich (text in German). *Z. angew. Meteorologie*, vol. 50, p. 257-271.

Hebner, E. (1928) The duration of the snow cover in Germany (text in German). *Forschungen z. deut. Landes u. Volkskunde*, vol. 26, no. 2, p. 101-168.

Hellmann, G. (1921) New investigations on precipitation conditions in Germany. Part 2: Snow conditions (text in German). *Sitzber. preuss. Akad. Wiss.*, p. 245-257.

Hendricks, R.L. and R.J. DeAngelis (1976) Seasonal snow accumulation, melt and water input – a New England model. *Journal of Applied Meteorology*, vol. 15, p. 717-727.

Huschke, R.E. (1959) Glossary of meteorology. American Meteorological Society, Boston.

Keeler, C.M. (1971) Snow and ice. *EOS, Transactions of American Geophysical Union*, vol. 52, no. 6.

Klute, F. (1911) Snow remnants in early summer in the Black Forest and the relation of their location to formerly glaciated areas (text in German). *Ber. naturforsch. Ges. Freiburg i. Br.*, vol. 19, p. 61-116.

Knepple, R. (1953) Winter in Mecklenburg (text in German). *Z. Meteorologie*, vol. 7, p. 298-307.

Küchler, A.W. (1967) *Vegetation mapping.* New York: Ronald Press Company.

Kuhnke, W. (1939) Heavy snowfalls in Germany with special reference to the snowstorm catastrophe of April 16, 1936 (text in German). *Meteorologische Z.*, vol. 56, p. 418-428.

Lachmann, G.F. (1902) The snow cover in Berlin (text in German). *Berliner Zweigver. Deut. Meteorologischen Ges.*, vol. 19, p. 9-26.

Lachmann, G. and G. Schwalbe (1916) The depth of the snow cover in northern Germany (text in German). *Meteorologische Z.*, vol. 33, p. 289-305.

Larsen, D. (1976) Allied team. *Soldiers*, March, p. 6-10.

Lauscher, F. (1969) Method for the estimation of the monthly snow cover in the Eastern Alps (text in German with English summary). *Wetter und Leben*, vol. 21, no. 8, p. 167-172.

Lautzenheiser, R.E. (1968) Snowfall, snowfall frequencies and snow cover data for New England. *Proceedings, 25th Meeting of Eastern Snow Conference*, Boston, Massachusetts.

Lengacker, F. (1910) Investigations on snow conditions in Southern Germany on the basis of observations from 1890-1900 (text in German). *Deut. Meteorologisches Jahrb. Bayern*, vol. 30, p. C1-C36.

Ludlum, D.M. (1977) The snowfall season of 1975-76. *Weatherwise*, p. 18-21.

MacDonald, C.B. (1973) The last offensive. The European theater of operations, U.S. Army in World War II. Office of the Chief of Military History, U.S. Army, Washington, D.C.

Malsch, W. (1923) Snow conditions in Baden (text in German). Thesis, University of Heidelberg, Germany.

McGinnis, D.F., J.A. Pritchard and D.R. Wiesnet (1975) Snow depth and snow extent using VHRR data from the NOAA-2 satellite. National Oceanic and Atmospheric Administration Technical Memorandum NESS 63.

McKay, G.A. and H.A. Thompson (1972) The role of snow and ice in hydrology. UNESCO-WMO-IAHS, *Proceedings of the Banff Symposia*, vol. 1, p. 598-607.

McMillan, M.C. and D.F. McGinnis (1975) Snowfall patterns near the Great Lakes. *Monthly Weather Review*, vol. 103, p. 837-838.

Meier, M.F. (1975) Application of remote sensing techniques to the study of seasonal snow cover. *Journal of Glaciology*, vol. 15, no. 73, p. 251-265.

Meissner, O. (1943) Relation between temperature and snowfall in the winter months in Berlin (text in German). *Z. angew. Meteorologie*, vol. 60, p. 16-26.

Metzler, H.K. (1935) Snow conditions at Brocken in the winter of 1934-35 (text in German). *Geograph. Wochenschr.*, vol. 3, p. 1111-1116.

Middleton, D. (1976) U.S. troops in West Germany test new tactics of flank attacks by small groups on "Soviet invaders." *New York Times*, 10 October 1976.

Mollwo, H. (1953) Snow-rich winters in the West German hill country (text in German). *Wetterkarte Deut. Wetterdienstes (Bad Kissingen)*, vol. 80, no. 1.

Naegler, W. (1943) Snow conditions in Dresden during the last 17 winters (text in German). *Z. angew. Meteorologie.*

New York Times (1975) *Atlas of the world.* New York: Times Book Company.

Paine, D.A. and M.L. Kaplan (1971) The parameterization and prediction of synoptic-scale influences on Great Lakes snowstorms. *Proceedings of the 28th Annual Eastern Snow Conference*, Fredericton, New Brunswick, Canada.

Peppler, A. (1934) Snow cover and skiing in the Black Forest (text in German). *Veröffentl. d. Badischen Landeswetterwarte*, no. 21, p. 92-108.

Pielke, R.A. and P. Mehring (1977) Use of mesoscale climatology in mountainous terrain to improve the spatial representation of mean monthly temperatures. *Monthly Weather Review*, vol. 105, no. 1, January 1977, p. 108-112.

Pleiss, H. (1961) Snowfall and snow cover [of Fichtelberg] (text in German). *Abhandl. Meteorol. Hydrol. Dienstes der DDR*, vol. 8, no. 62, p. 196-207.

Quinn, W.F. and E.F. Lobacz (1962) Frost penetration beneath concrete slabs maintained free of snow and ice, with and without insulation. Highway Research Board Bulletin 331, p. 98-115.

Rachner, M. (1964) The significance of snow-density measurements in hydrometeorology. *Z. Meteorologie*, vol. 17, no. 7-8, p. 234-239.

Rango, A. (Ed.) (1975) Operational applications of satellite snowcover observations. National Aeronautics and Space Administration Report SP-391, Washington, D.C.

Rango, A., V.V. Salomonson and J.L. Foster (1977) Seasonal streamflow estimation in the Himalayan region employing meteorological satellite snow cover observations. *Water Resources Research*, vol. 13, no. 1, p. 109-112.

Reichel, E. (1965) Frequency and distribution of extreme cases of precipitation and snowfall in the Bavarian Alpine "Vorland" (text in German with English abstract). *Wetter und Leben*, vol. 17, no. 1-2, p. 14-26.

Reichsamt für Wetterdienst (1942) Comparison of snow conditions of Russia, Poland, and North Germany, Berlin.

Reinhard, H. (1952) Snow cover conditions in Mecklenburg (text in German). *Angew. Meteorologie*, vol. 1, p. 114-119.

Rychetnik, J. (1971) Snow and avalanches in the Swiss Alps: Winter 1970-71 (text in German). Eidgenossisches Institut fur Schnee und Lawinenforschung, *Winterberichte*, no. 35.

Sanger, F.J. (1968) Ground freezing in construction. *Journal of Soil Mechanics and Foundations Division*, vol. 94, no. SM-1.

Schreiber, P. (1904) Snow conditions in the Fichtelberg Region on March 9 and 10, 1904 (text in German). *Wetter*, vol. 21, p. 107-113.

Schulz, L. (1952) The snow cover in the Oberharz (text in German). *Ann. Meteorologie*, vol. 5, p. 190-191.

Schulz, L. (1965) The causes of light- and heavy-snow winters in the Harz (text in German). *Meteorol. Rundsch.*, vol. 18, no. 3, p. 91-92.

Schwalbe, G. (1936) The amount of snow in the total amount of precipitation in Germany (text in German). *Z. angew. Meteorologie*, vol. 53, p. 105-111.

Sieberg, A.H. (1902) Snow conditions in Aachen and their practical aspects (text in German). *Deut. meteorologisches Jahrb. Aachen*, vol. 7, no. 36-42.

Soldiers (1975) The lumberjacks. vol. 30, no. 11.

Stegers, J. (1913) Contributions to the knowledge of snow cover depth and duration in Northern Germany (text in German). *Erfurt: Ohlenroth'sche Buchdruckerei Georg Richters.*

Strong, A.E., E.P. McClain and D.F. McGinnis (1971) Detection of thawing snow and ice packs through combined use of visible and near-infrared measurements from earth satellites. *Monthly Weather Review*, vol. 99, no. 11, p. 828-830.

Swanson, R.H. (1970) Local snow distribution is not a function of local topography under continuous tree cover. *Journal of Hydrology*, (New Zealand), vol. 9, no. 2, p. 292-297.

Thom, H.C.S. (1957) Probabilities of one-inch snowfall thresholds for the United States. *Monthly Weather Review*, vol. 85, no. 8, Dept. of Commerce, Washington, D.C.

Thomas, K.B. and G. Alt (1972) Ice and snow on the German Federal Highways in the winter of 1970-71. *Strasse und Autobahn*, vol. 23, no. 1, p. 27-31.

UNESCO-IASH-WMO (1970) Seasonal snow cover. A guide for measurement, compilation and assemblage of data. Contribution to the International Hydrological Decade, Technical paper in Hydrology no. 2, United Nations Educational, Scientific, and Cultural Organization, International Association of Scientific Hydrology, World Meteorological Organization.

U.S. Air Force (1970-1972) Air weather service (AWS) climatic briefs. Climatic summaries for stations in Germany or AWS Form 62, prepared by U.S. Air Force Environmental Technical Applications Center.

U.S. Air Force (1974) Regular uniform summaries of surface weather observations. Air Weather Service, USAF-ETAC, Scott Air Force Base, Illinois.

U.S. Army (1965) Pavement design for frost conditions – soils and geology. Technical Manual no. TM5-818-2.

U.S. Army and Air Force (1966a) Arctic and subarctic construction general provisions. Technical Manual no. 5-852-1 and Air Force Manual no. 88-19, chapter 1.

U.S. Army and Air Force (1966b) Calculation methods for determination of depths of freeze and thaw in soils: Arctic and subarctic construction. Technical Manual 5-852-6, AFM 88-19, chapter 6, Washington, D.C.

U.S. Army Arctic Construction and Frost Effects Laboratory (1954) Depth of snow cover in the Northern Hemisphere. Corps of Engineers, U.S. Army, New England Division, ACFEL Technical Report 49.

U.S. Army Cold Regions Research and Engineering Laboratory (1951-78) Bibliography on Cold Regions Science and Technology (Geza T. Thuronyi, Ed.). CRREL Report 12, vol. 1-32.

U.S. Dept. of Commerce (1940) Climatic statistics for selected stations in Germany. U.S. Weather Bureau, Statistics Division, Special Report 101, Washington, D.C.

U.S. Dept. of Commerce (1956) Climatic summary of the U.S. – Supplement for 1931 through 1952. Climatography of the U.S. No. 11, U.S. Government Printing Office, Washington, D.C.

U.S. Dept. of Commerce (1964) Climatic summary of the U.S. – Supplement for 1951 through 1960. Climatography of the U.S. No. 86, U.S. Government Printing Office, Washington, D.C.

U.S. Dept. of Commerce (1966) World weather records 1951-1960. Vol. 2: Europe. Environmental Science Services Administration, Environmental Data Services, Washington, D.C.

U.S. Dept. of Commerce (1973) U.S. Naval Weather Service, World-wide Airfield Summaries. Vol. X and XI, U.S. Naval Weather Service and the U.S. Air Force Environmental Technical Applications Center (ETAC).

U.S. Dept. of Commerce (1974) Monthly climatic data for the world. National Climatic Center, vol. 27, no. 1-12.

Weickmann, H.K., J. Jiusto, G. McVehil, R. Pilie and J. Warburton (1970) The Great Lakes project. *Proceedings, of the 27th Annual Eastern Snow Conference*, Albany, New York, Feb. 1970.

Weigel, W. (1960) The measurement of snow cover on the Brocken Mountain (text in German with English summary). *Z. Meteorologie*, vol. 14, no. 7/9, p. 191-195.

Weischet, W. (1950) The snow cover of the Rheinish Slate Mountains in relation to synoptic meteorological conditions (text in German). *Decheniana*, vol. 104, p. 104-144.

Wiesnet, D.R. and M. Matson (1976) A possible forecasting technique for winter snow cover in the Northern Hemisphere and Eurasia. *Monthly Weather Review*, vol. 104, no. 7, p. 828-835.

World Meteorological Organization (1970) Climatic atlas of Europe. Part I: Maps of mean temperature and precipitation. WMO, UNESCO, Cartographia, Budapest.

World Meteorological Organization (1973) Snow survey from earth satellites: A technical review of methods. Secretariat of the World Meteorological Organization, Geneva, Switzerland.

APPENDIX A: INTERPRETATION OF SNOW COVER BY SATELLITE

In 1968 the World Meteorological Organization (WMO) sponsored a project on snow studies by satellite, which was concluded in 1973 with the publication of a technical review of methods for surveying the snow cover from earth satellites (WMO 1973). The report provides background information on the satellite and sensor systems available for snow studies, and describes the various approaches or methods used by seven nations to interpret the snow cover and the results obtained from their studies. The following quotation is taken from the summary given in that report:

> The approaches used are grouped in the report as follows: 1) direct optical-mechanical methods, 2) optical-electronic methods, and 3) automated-electronic methods. The first of these methods ... employs optical and/or mechanical assistance, but its basic elements are a photographic image and man. The second method ... emphasizes elimination of the human eye in favor of a densitometer for scanning the image or use of computer processing of the satellite signal to eliminate variations that can be introduced by photographic processing. [In] the third method ... the entire process of determining the snow line or areal extent of the snow cover is objective and accomplished entirely by computer.
>
> Tests of the accuracy of satellite-derived snow lines were carried out by only a few of the countries and for only some of the [above] methods ... The accuracy, and often even the method or type, of verifying information is generally not known, and this factor should be kept in mind. In non-mountainous terrain [in the U.S. and Canada] the accuracy in location of the snow line has been cited as ± 20 km. Most verifying figures in mountainous areas are cited in terms of the elevation of the snow line. Two independent estimates were remarkably close, 165-200 m and 150-200 m, respectively, although one country claimed 80-165 m under some conditions. The accuracy tests ... refer only to optical-mechanical methods, for none was available for the optical-electrical methods. The only tests performed for an automated electronic method ... resulted in the statement that accuracy in positioning the snow line was within the limits of uncertainty in placing the line from analysis of surface reports.

Recent work indicates that thermal infrared measurements from satellites are potentially useful in snow studies. For example, one study provides some evidence that the combined use of satellite observations in the visible and near-infrared part of the spectrum enables detection of thawing snow and ice surfaces (Strong et al. 1971).

Analysis of satellite imagery to determine snow-cover distribution has been conducted for many parts of the globe. Winter season snow and ice charts of the Northern Hemisphere based on satellite data from 1966 through 1975 were examined to determine the extent and area of snow cover in Eurasia and North America (Wiesnet and Matson 1976). According to the authors, results of a regression analysis using an antecedent snow-cover technique yielded equations with correlation coefficients significant enough to have possible applications for 30- 60- and 90-day forecasting of seasonal, hemispheric, and continental snow cover. Another study (McGinnis et al. 1975) attempts to determine the depth of the snow cover using very high resolution radiometer data from the NOAA-2 satellite.

Similar but more detailed satellite studies of the snow cover have been conducted in areas such as the Swiss Alps (Haefner et al. 1974), the Himalayas (Rango et al. 1977), the Sierra Mountain Range in Southern California (Barnes and Bowley 1970), the Adirondacks in New York (Eschner et al. 1977), the city of Chicago and vicinity (Bunting and Lamb 1968), and the Buffalo region (Dietz and Kolker 1975). The Himalayan, Alps, Sierra and Adirondack mountain studies investigated the areal extent and accumulation of snow in large high-altitude watersheds for specific hydrologic information in remote areas useful in streamflow and runoff estimates. Investigations of satellite imagery of the snow cover in more localized areas, such as cities, are beneficial in weather prediction and analysis, and for specific purposes such as snow removal and control on roads and highways. For the purposes of military operations in, for example, the cross-country movement of men and machines in winter, localized studies would be more relevant with respect to determining whether a region is covered with snow.

An excellent compilation of reports centered on the operational applications of satellite snow-cover observations is contained in a proceedings volume of a workshop held in South Lake Tahoe, California, in 1975 (Rango 1975). Over 25 scientific papers on the photointerpretation of LANDSAT and NOAA satellite data on snow cover are included in this volume. It also contains a number of reports on new advances in the extraction of snowpack parameters, other than snow extent, through the use of a variety of remote sensors, and covers the employment of computer and digital techniques in imagery analysis. Additional studies on the computer-digital methods are given by Alföldi (1976), Barnes and Bowley (1974), Meier (1975), and Anderson et al. (1974).

Although no attempt is made in this study to analyze satellite photographic images of snow cover in East or West Germany, a series of NASA LANDSAT photoimages were obtained for the area taken during the winters of 1972-73 and 1973-74 (Goddard Space Flight Center 1975). From an inspection of available photo images, in which location, time of year, clarity, and cloudiness were considered, 20 photos were purchased. Of these, about half provided good to excellent imagery of the snow cover. Four of the best photo images obtained are presented here in order to show how well the areal extent of the snow cover can be determined from exceptionally clear satellite photo images.

The multispectral scanner (MSS) on the LANDSAT satellites senses reflected light in four spectral bands ranging from 0.5 to 1.1 μm. The satellites circle the earth in a near polar orbit 14 times per day at about a 920-km altitude (Rango 1975). The black and white photo images processed at the NASA Goddard Space Flight Center cover an area of about 185 km on each side. Two photo images of MSS band 5 (0.6-0.7 μm) taken on 17 December 1972 and 17 March 1973 are shown in Figures A1 and A2, respectively. The area shown in these two photos is almost exactly the same and is outlined in Figure A3. The region includes a small portion of southeastern West Germany and parts of Austria and Switzerland. The snow cover in the Alps on these photo images is clearly marked. In Figure A1 the snow line in the mountain valleys appears to be higher in elevation in December 1972 than it is toward the end of winter, i.e. March 1973 (Figure A2). The March 1973 photo image shows less shadow due to the higher sun elevation and also indicates advanced icing and additional snow cover on the rivers. It also shows what appear to be snow-free regions on some of the lower portions of the mountain slopes along the steep dendritic-shaped valleys. Figure A2 also shows two ice-free bodies of water (Ammersee and Warmsee) located southwest of München in the upper portion of the photo. Clouds over this area obscure these lakes on 17 December 1972 (Fig. A1).

The MSS band 7 (0.8-1.1 μm) image on 17 March 1973 is shown in Figure A4. Although this photographic image allows better determination of the open channels of water in, for example, the rivers at the valley floor, edges of the snow line are not quite as easily identified. This band, therefore, would not be as useful in satellite imagery studies on delineating position and changes in the snow line. Another MSS band 5 photoimage (Fig. A5), also taken on 17 March 1973, covers an area immediately north of the region discussed previously (see Fig. A3). Parts of the two lakes identified in Figure A2 appear in Figure A5. Figure A5 includes more areas of lower elevation and a larger mixture of 1) fresh or undisturbed snow cover (bright zones), 2) older, partly melted or deteriorated snow (gray zones), and 3) regions of no snow or possibly forested areas (black zones). The river valleys and open rivers, as well as the snow-free portions of larger cities (e.g. München), are easily identified in the photograph. More detailed analysis of the snow type and distribution can be obtained using the various techniques described in the number of references given earlier in this section.

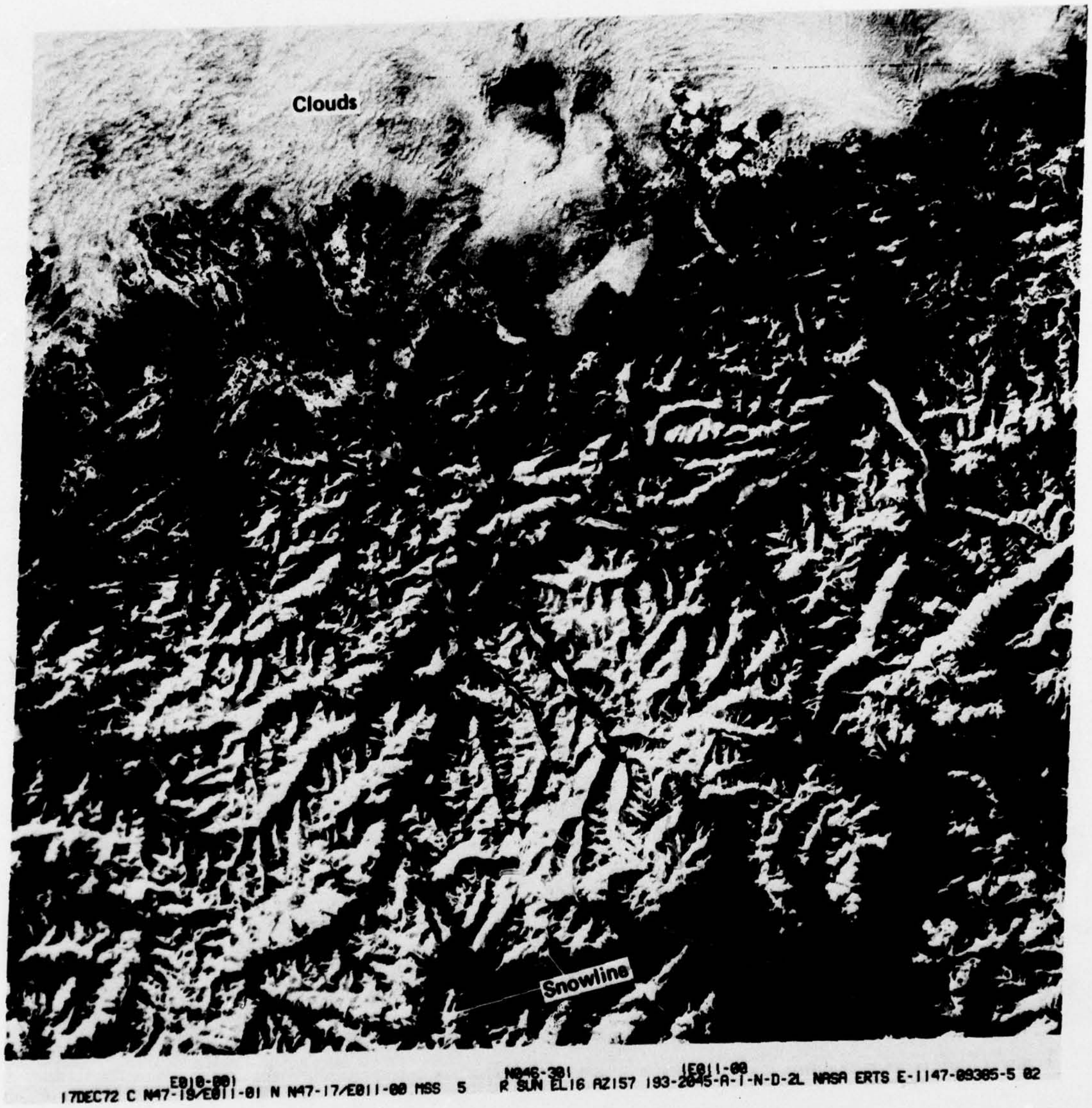


Figure A1. LANDSAT MSS band 5 image obtained over West Germany on 17 December at 0938 Greenwich Mean Time (GMT).

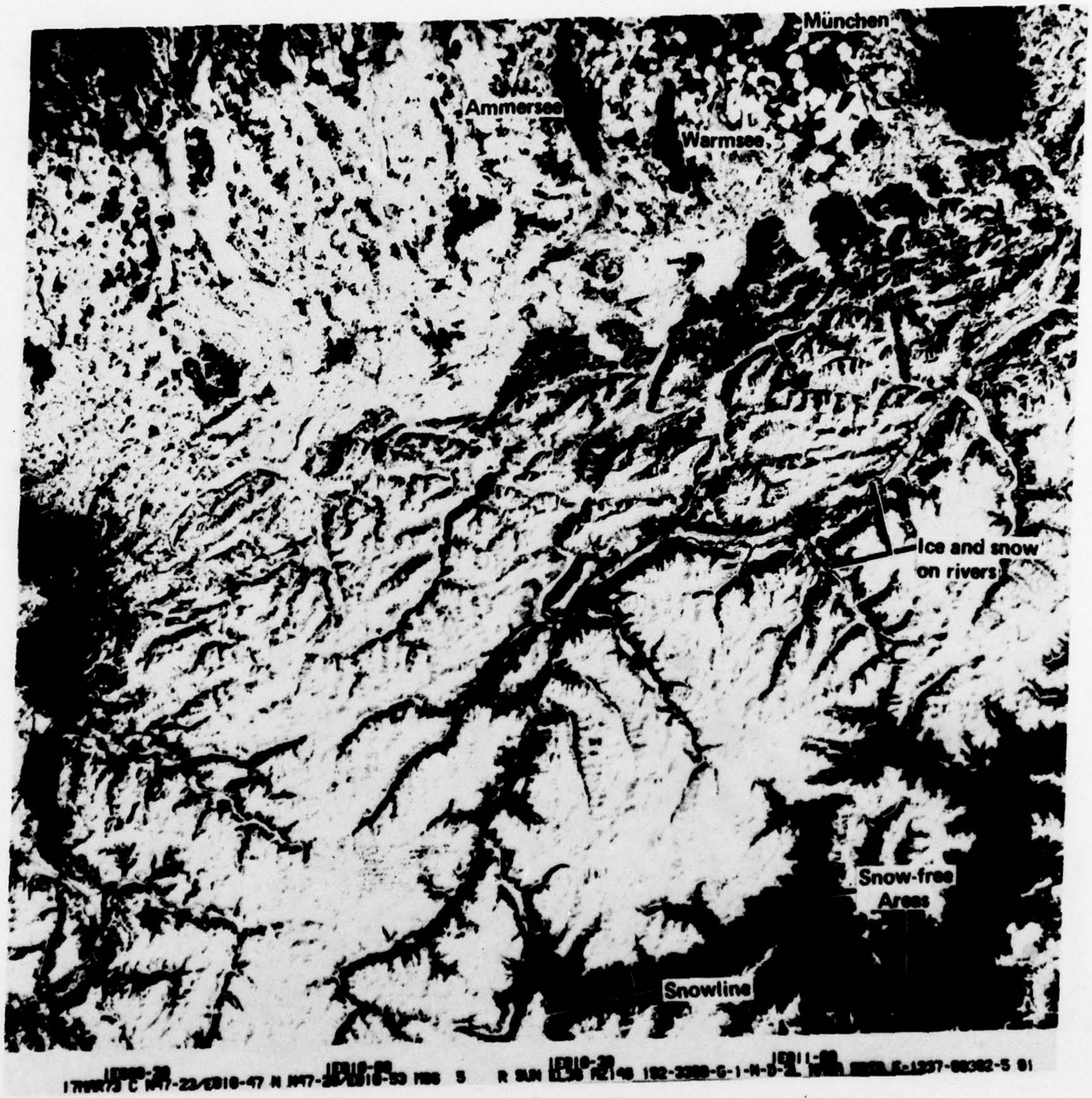


Figure A2. LANDSAT MSS band 5 image obtained over West Germany on 17 March 1973 at 0939 GMT.

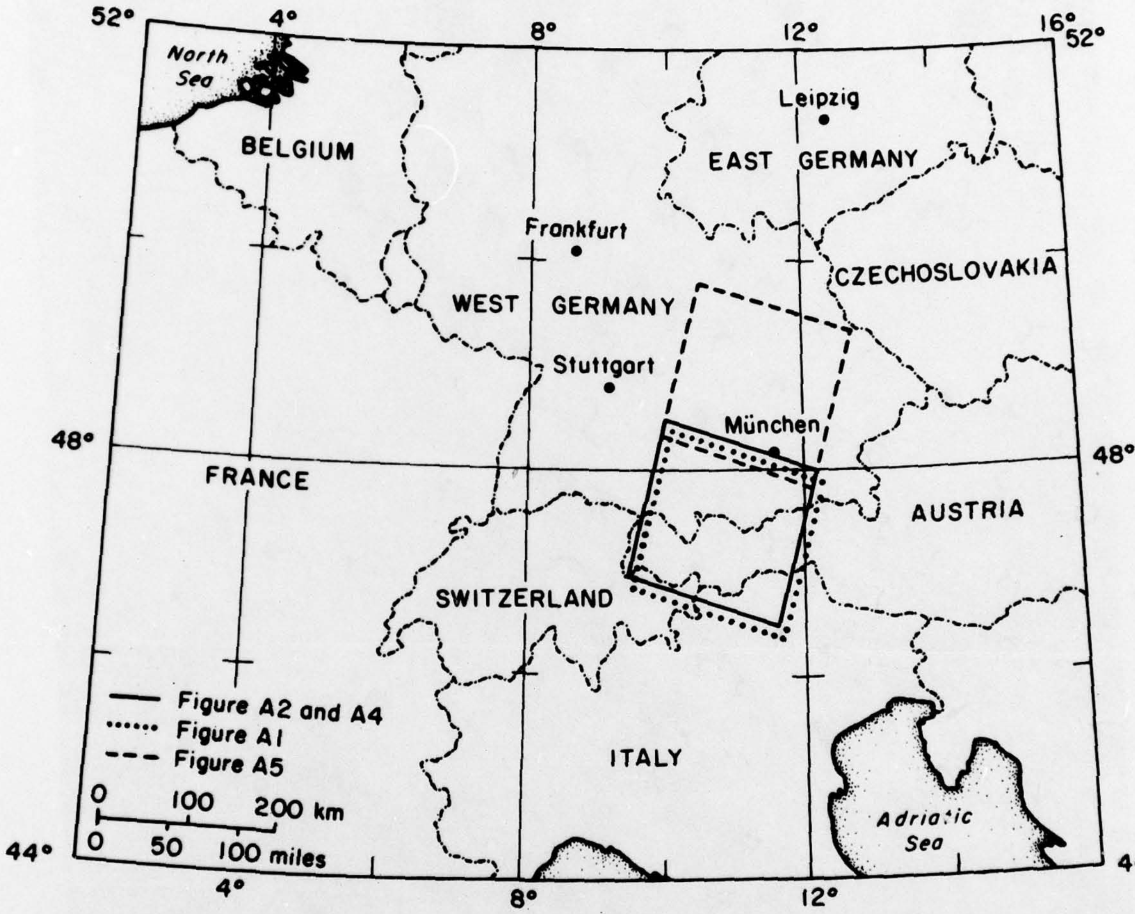


Figure A3. Location of areas shown in Figures A1, A2, A4 and A5.

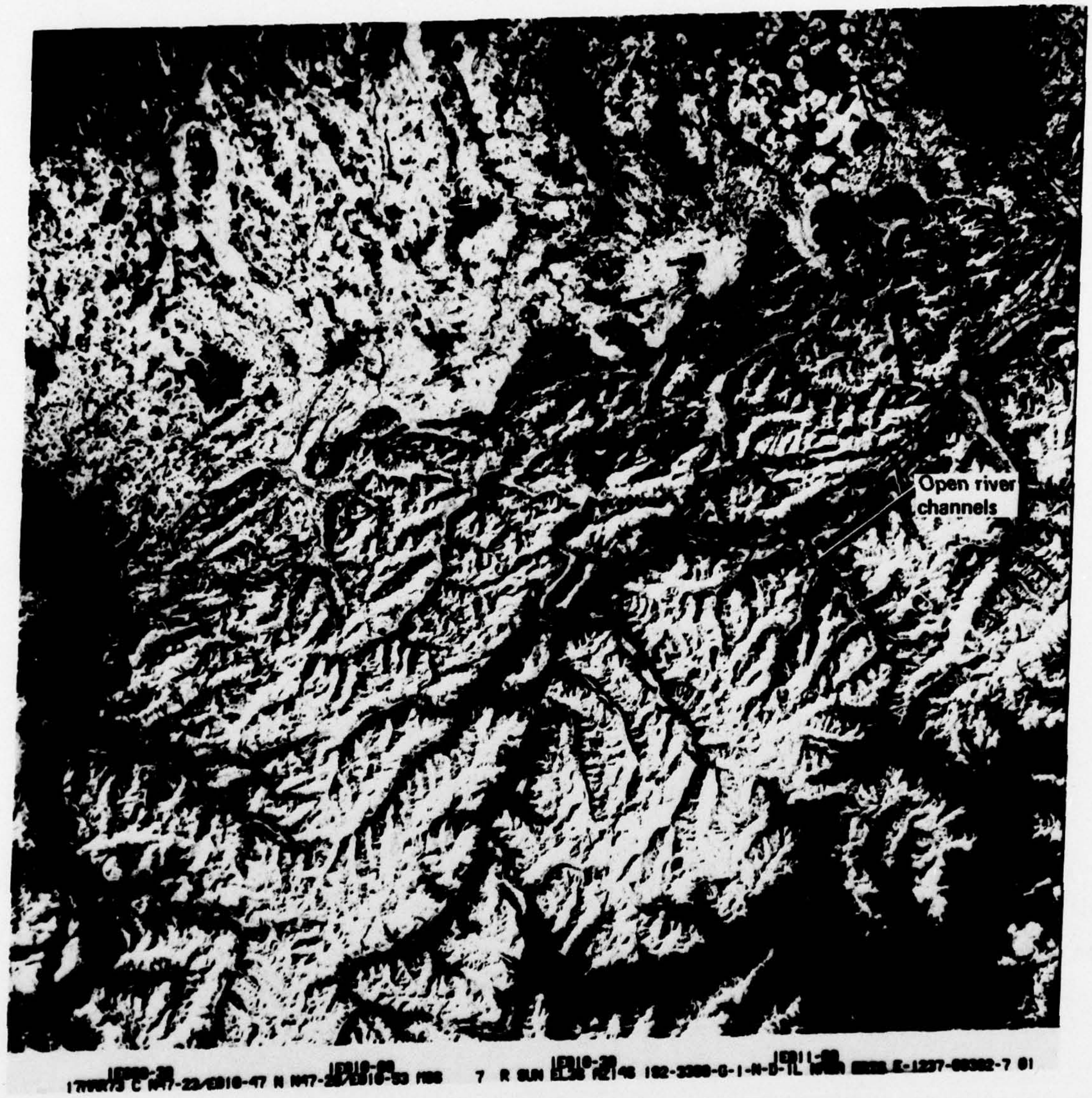


Figure A4. LANDSAT MSS band 7 image obtained over West Germany on 17 March 1973 at 0939 GMT.

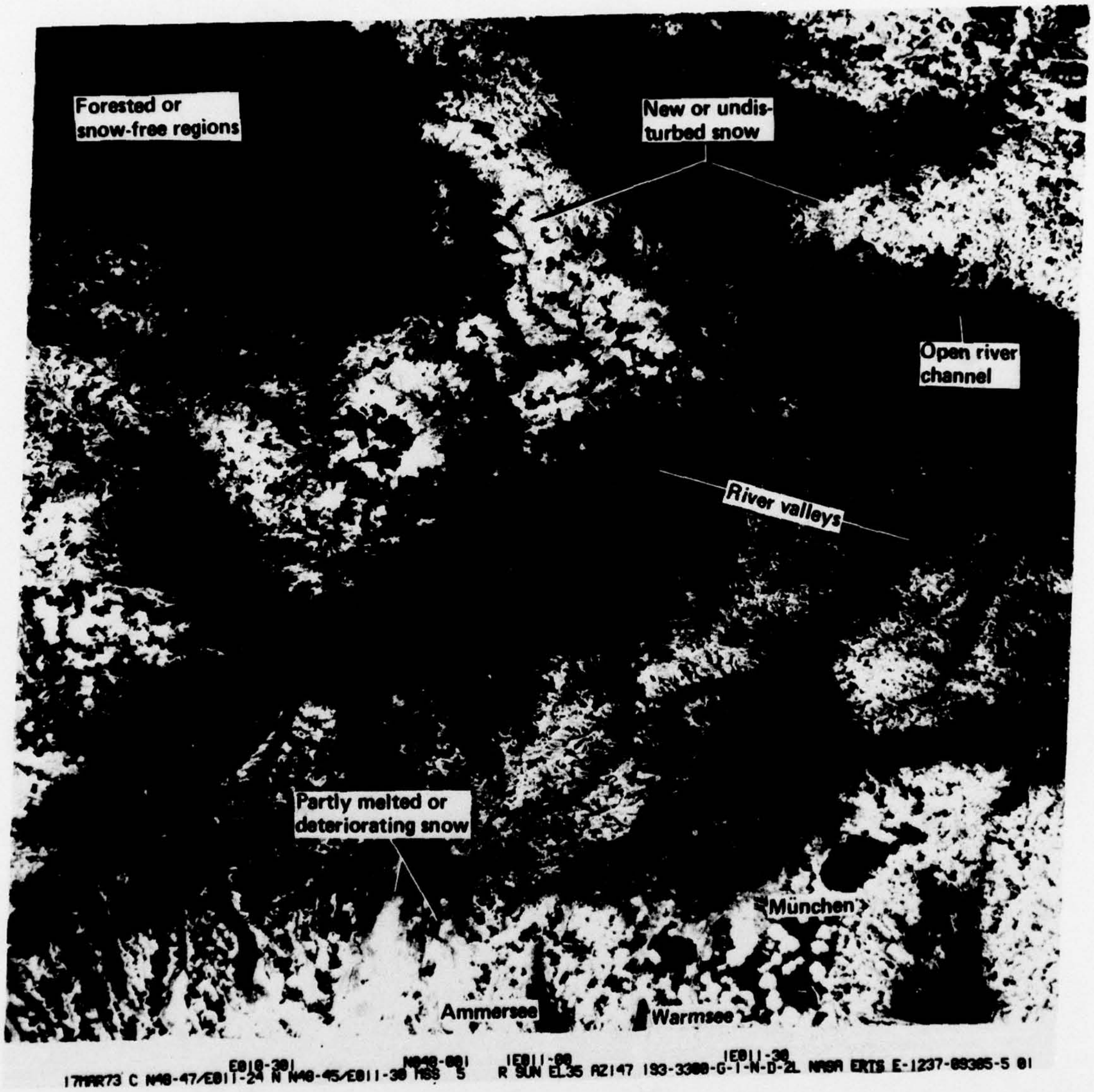
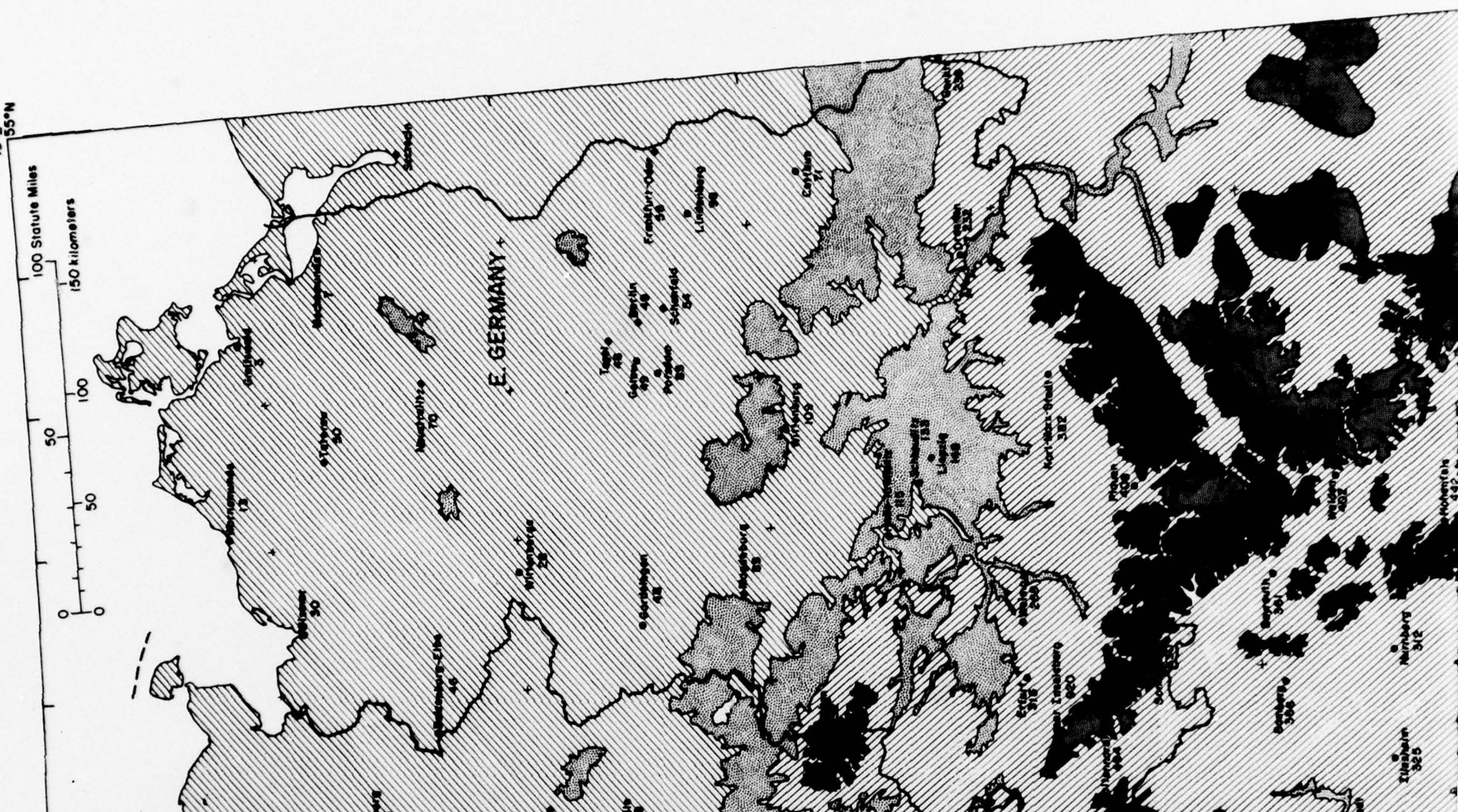


Figure A5. LANDSAT MSS band 5 image obtained over West Germany on 17 March 1973 at 0938 GMT.


15°E 55°N
100 Statute Miles
150 kilometers
0 50 100
0 50
E. GERMANY
W. GERMANY
Elev. (m)
0 to 100
100 to 200
200 to 500
500 to 1000
> 1000
6°E
54°N
53°N
52°N
51°N
50°N

APPENDIX B. CONTOUR, STATION ELEVATION AND AJAT MAPS FOR EAST AND WEST GERMANY.

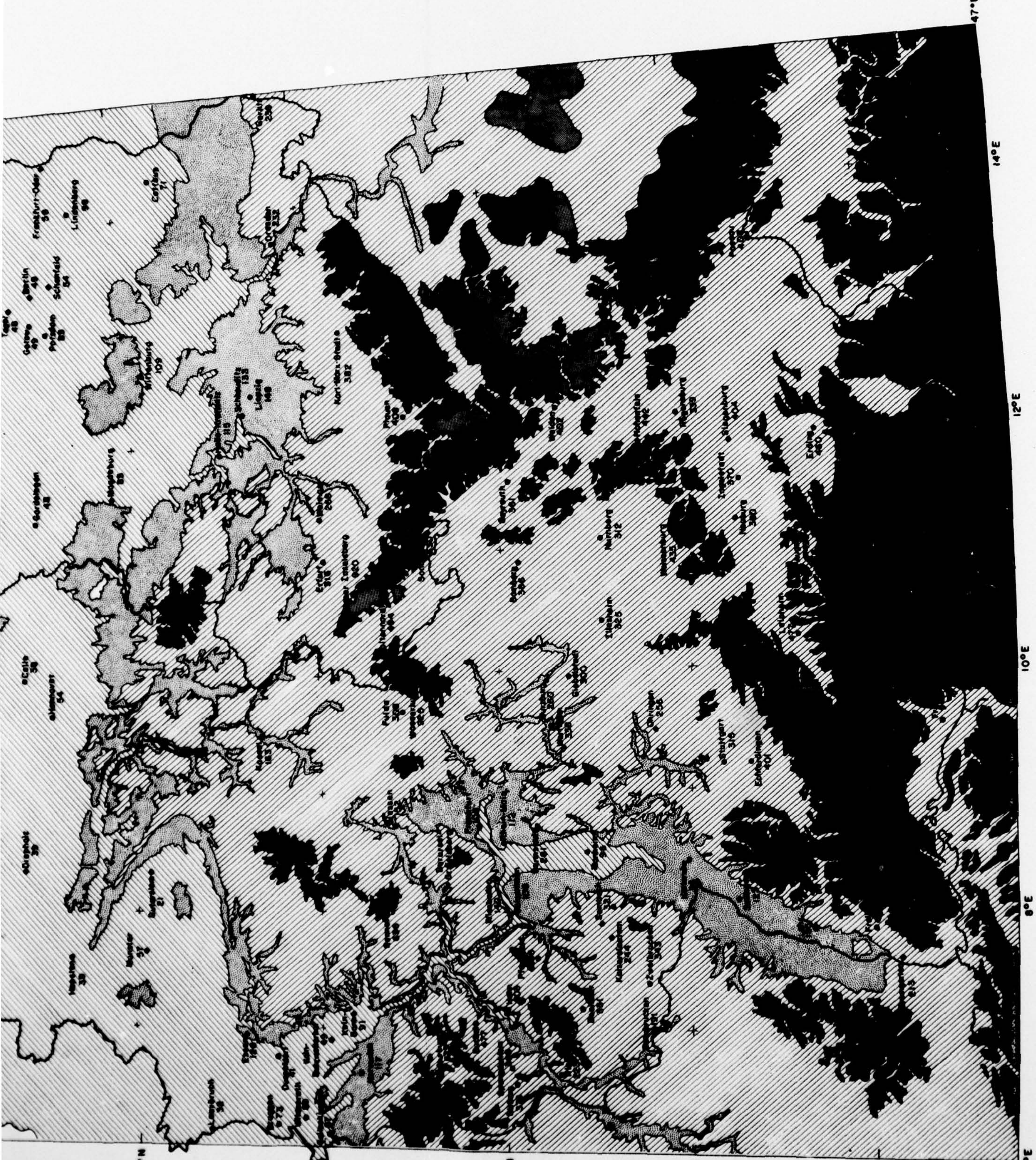


Figure B1. Station locations and elevations (meters above sea level).

2

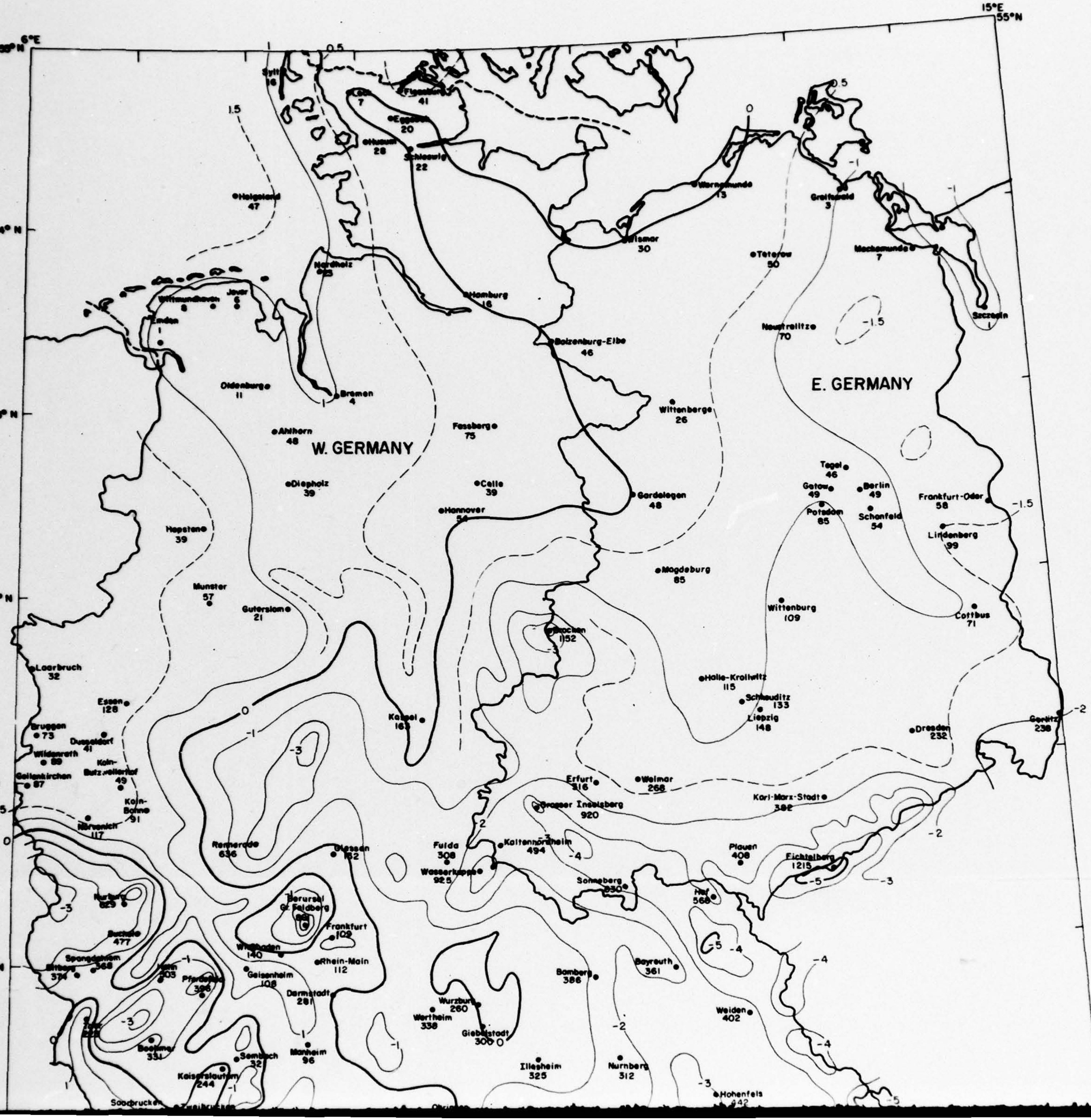
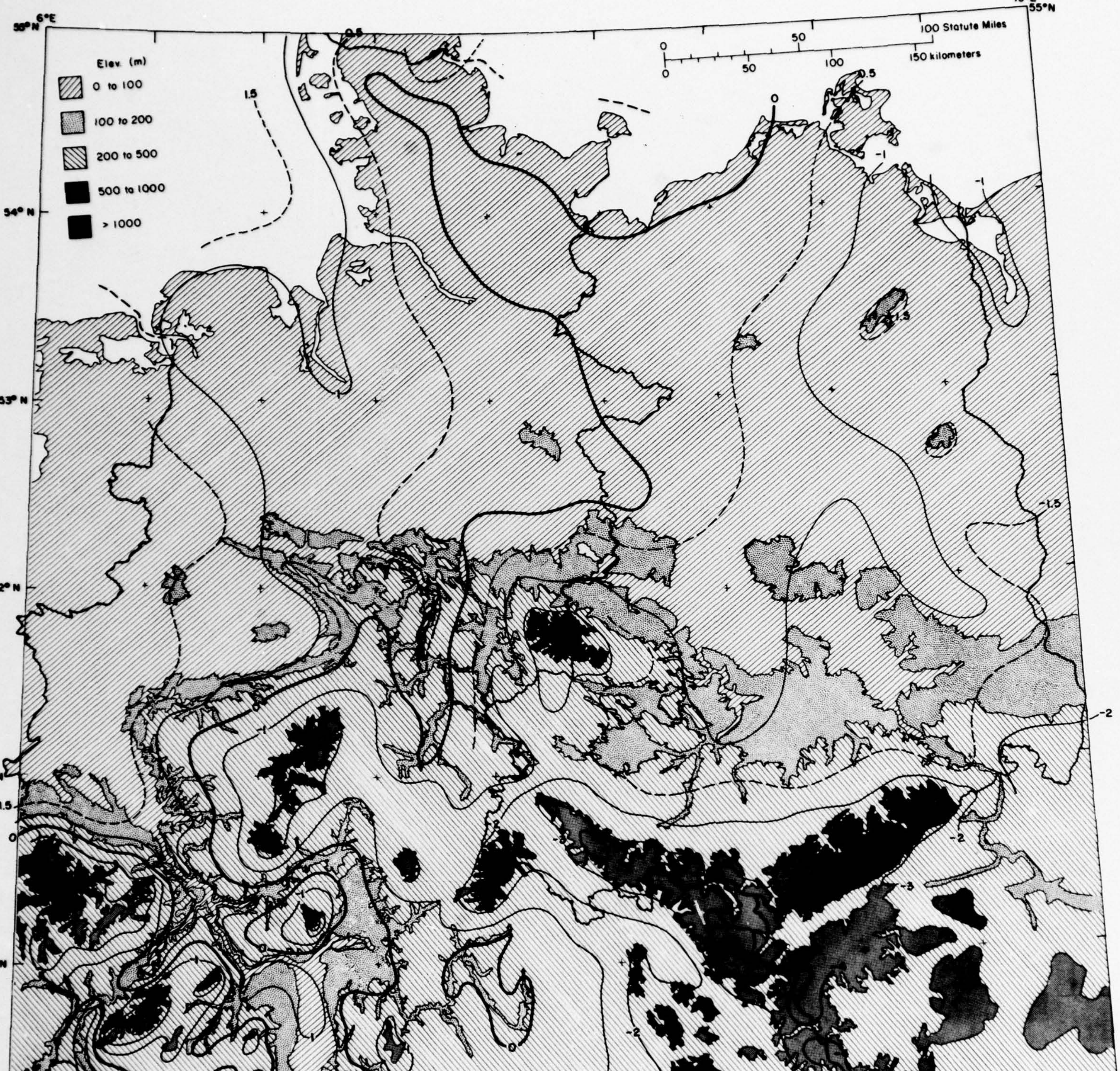

E. GERMANY
W. GERMANY
Sylt 16
Helgoland 47
Husum 28
Eggebek 20
Schleswig 22
Flensburg 41
Warnemunde 13
Greifswald 3
Wismar 30
Teterow 50
Meckermunde 7
Nordholz
Hamburg 16
Szczecin
Wittmundhaven 8
Jever 6
Emden
Boizenburg-Elbe 46
Neustrelitz 70
Oldenburg 11
Bremen 4
Wittenberge 26
Ahlhorn 48
Fassberg 75
Tegel 46
Gatow 49
Berlin 49
Diepholz 39
Celle 39
Gardelegen 48
Potsdam 65
Schonfeld 54
Frankfurt-Oder 58
Hannover 54
Lindenberg 99
Hopsten 39
Magdeburg 85
Munster 57
Guterslohe 21
Wittenburg 109
Cottbus 71
Brocken 1152
Laarbruch 32
Halle-Kroliwitz 115
Schkeuditz 133
Leipzig 148
Essen 128
Kassel 163
Bruggen 73
Dusseldorf 41
Dresden 232
Gorlitz 238
Wildenrath 89
Koln-Butzweilerhof 49
Erfurt 316
Weimar 268
Geilenkirchen 87
Karl-Marx-Stadt 382
Koln-Bonne 91
Grosser Inselsberg 920
Norvenich 117
Kaltennordheim 494
Fulda 308
Rennerode 636
Giessen 182
Plauen 408
Fichtelberg 1215
Wasserkuppe 925
Sonneberg 630
Hof 568
Oberursel
Gr Feldberg
Frankfurt 102
Buchel 477
Wiesbaden 140
Rhein-Main 112
Spangdahlem 368
Bitburg 374
Hahn 503
Pferdsfeld 386
Geisenheim 108
Darmstadt 281
Bamberg 386
Bayreuth 361
Wurzburg 260
Wertheim 338
Weiden 402
Giebelstadt 300
Baumholder 331
Manheim 96
Sembach 32
Illesheim 325
Nurnberg 312
Kaiserslautern 244
Hohenfels 442
Saarbrucken
Zweibrucken
6°E
15°E
55°N
54° N
53° N
52° N
51° N
50° N
1.5
1
0.5
0
-1
-1.5
-2
-3
-4
-5

Figure B2. Station locations and AJAT (average January air temperature) isolines (°C).



Elev. (m)
0 to 100
100 to 200
200 to 500
500 to 1000
> 1000
100 Statute Miles
150 kilometers
0
50
100
15°E
55°N
6°E
55°N
54° N
53° N
52° N
51° N
50° N
1.5
0.5
0
-1
-1.5
-2
-3

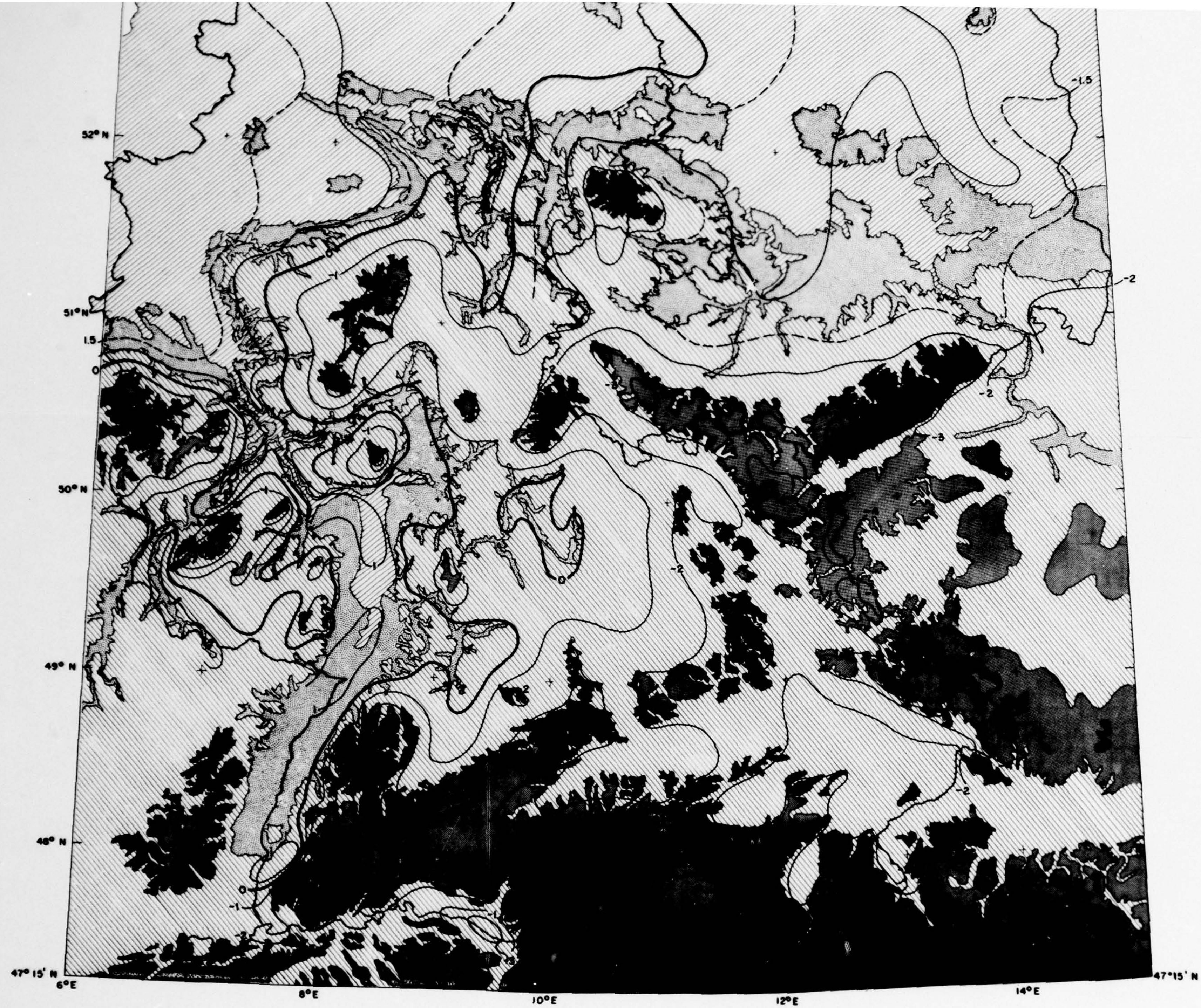
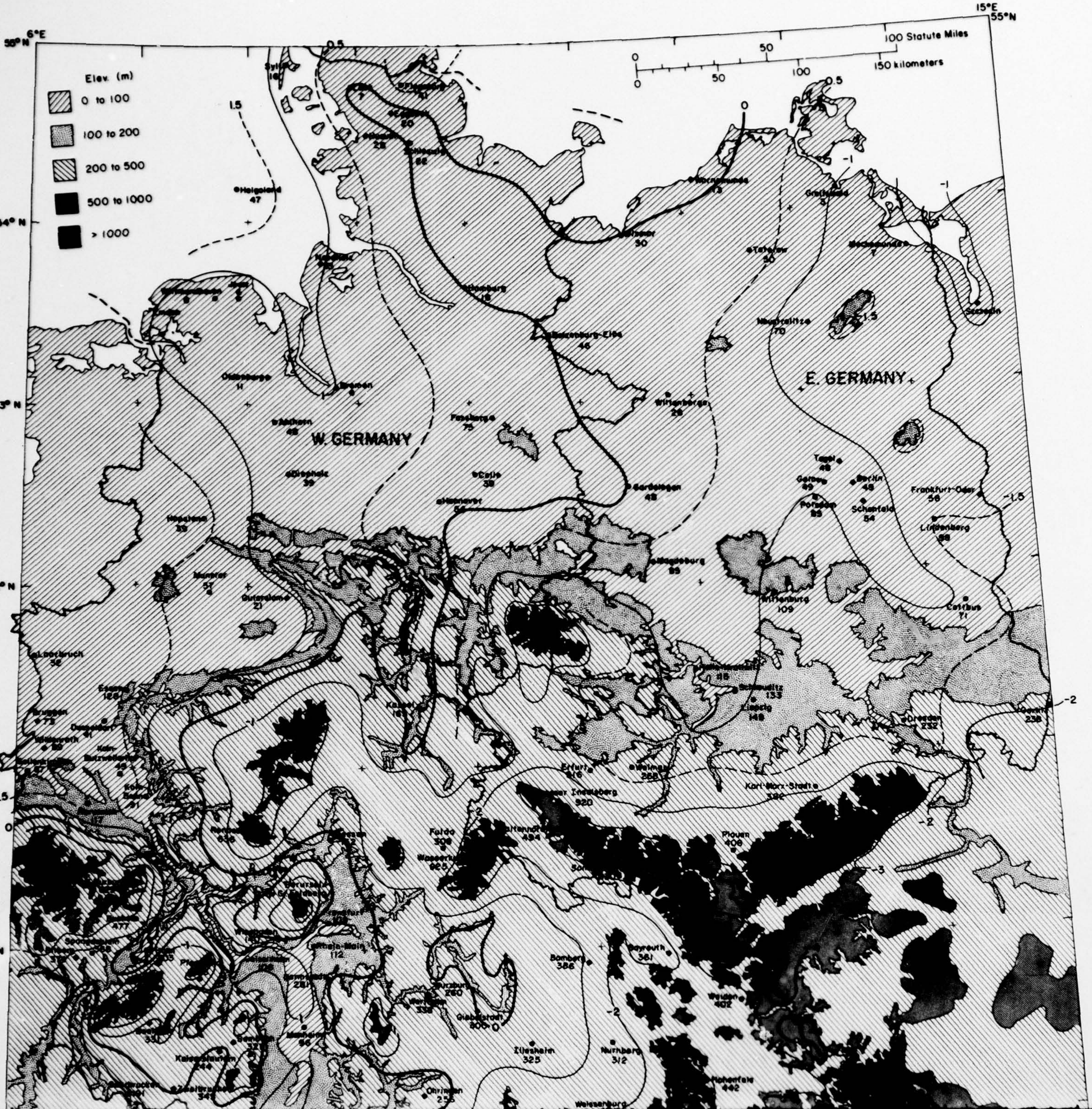


Figure B3. Elevations (m) and AJAT isolines (°C).



6°E
55°N
15°E
55°N
100 Statute Miles
150 kilometers
Elev. (m)
0 to 100
100 to 200
200 to 500
500 to 1000
> 1000
54° N
53° N
52° N
51° N
50° N
E. GERMANY
W. GERMANY
Helgoland
47
Oldenburg
11
Bremen
Wittenberge
26
Neustrelitz
70
Berlin
48
Potsdam
Schönefeld
54
Frankfurt-Oder
56
Lindenberg
Cottbus
71
Magdeburg
Wittenburg
109
Leipzig
Dresden
232
Erfurt
Karl-Marx-Stadt
Plauen
Fulda
Bamberg
386
Bayreuth
361
Nurnberg
312
Hohenfels
442
Weissenburg
Zilsheim
325
Würzburg
Frankfurt
Essen
Düsseldorf
Celle
Tegel
Stettin
Greifswald
Wismar

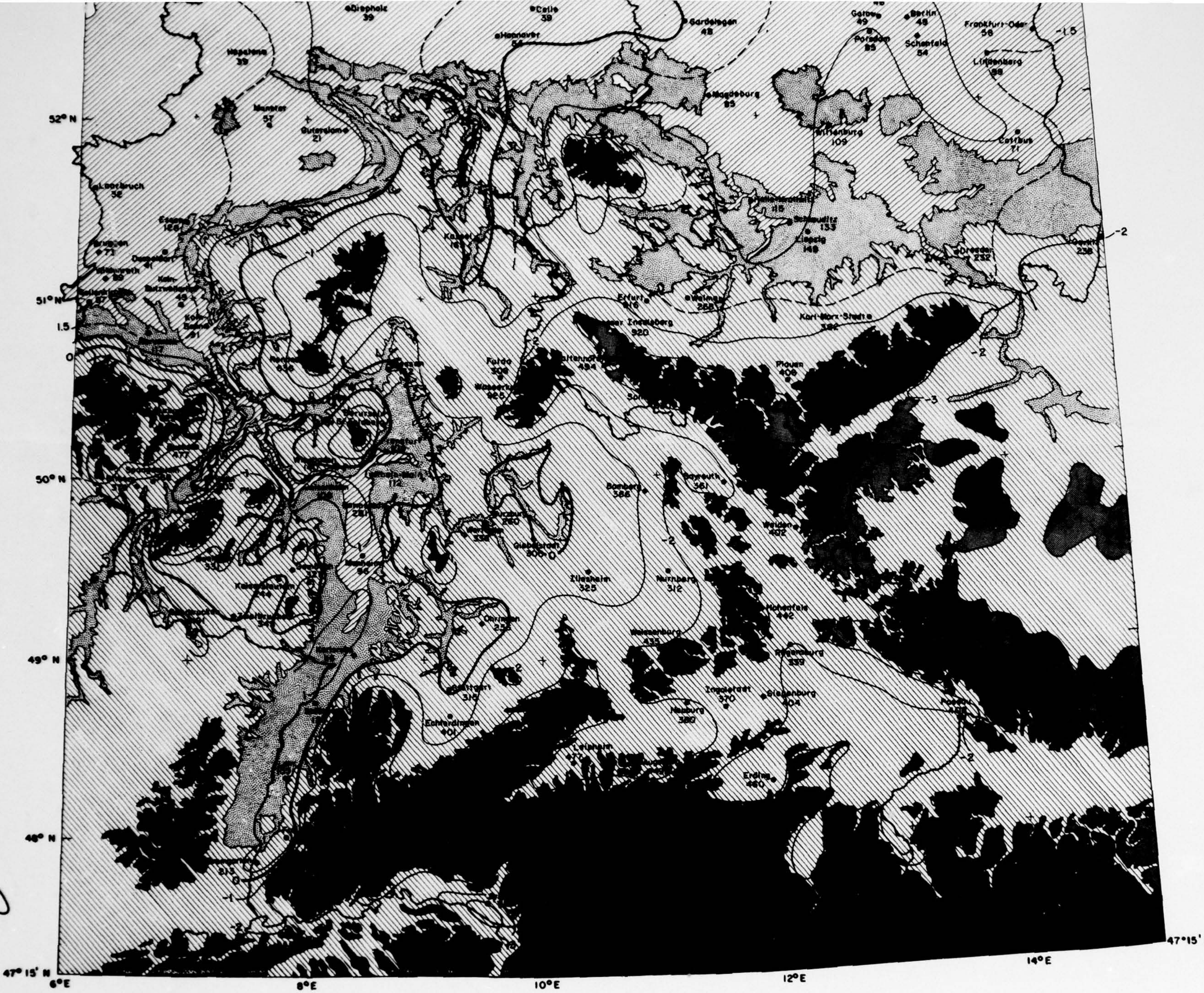


Figure B4. Station locations, elevations (m) and AJAT isolines (°C).

(From CRREL Report 78-21.)

2

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Bilello, Michael A.

Analysis of the midwinter temperature regime and snow occurrence in Germany / by Michael A. Bilello and G. Cameron Appel. Hanover, N.H.: U.S. Cold Regions Research and Engineering Laboratory; Springfield, Va.: available from National Technical Information Service, 1978.

v, 48 p., illus.; 27 cm. (CRREL Report 78-21.)

Prepared for Directorate of Facilities Engineering - Office, Chief of Engineers by Corps of Engineers, U.S. Army Cold Regions Research and Engineering Laboratory under DA Project 4A762730AT42.

Bibliography: p. 29.

1. Cold regions. 2. Germany (East and West). 3. Meteorological data. 4. Snow. 5. Temperature history. I. G. Cameron Appel, joint author. II. Army Cold Regions Research Research and Engineering Laboratory, Hanover, N.H. III. Series: CRREL Report 78-~~16.~~
21